VOL. I. 1891.

PROCEEDINGS

OF THE

ELECTRICAL SECTION

OF THE

FRANKLIN INSTITUTE

PHILADELPHIA
FRANKLIN INSTITUTE, 15 SOUTH SEVENTH STREET
1892.

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Vol. I.—January to December, 1891.

PHILADELPHIA:
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Vol. I, 1891.

By-Laws

of the

Electrical Section

of the

Franklin Institute.

ARTICLE I.

MEMBERSHIP.

SECTION 1. In accordance with article xi, section 4, of the by-laws of the institute, only members of the institute may be elected to membership in the section, but sections are empowered to appoint associates, corresponding members and honorary members, provided that such appointments are sanctioned by the board of managers. Associates shall have the privilege of attending the meetings of the section, and of participating in its scientific discussions, but shall not be entitled to vote.

SEC. 2. A committee of admissions shall consist of seven members. They shall be appointed by the president annually. Four members shall constitute a quorum at all meetings of this committee. The adverse vote of two members shall be a rejection of a candidate. Applications for admission to the section shall be in writing, and signed by a member of the section. These shall be referred to the committee, after having been read before the section at a stated meeting. It shall be the duty of the committee, after careful consideration of the fitness of a candidate, to

vote on each name separately by ballot. This proceeding shall be secret and confidential. The committee shall send to the secretary of the section the names and addresses of the candidates elected. This committee shall have power to make its own rules of procedure.

SEC. 3. Any member-elect who shall not signify to the secretary his acceptance of membership within sixty days after notice of his election, shall be considered as having declined the same; which fact shall be duly recorded and reported to the section.

SEC. 4. If any member shall be one year in arrears for dues to the section, and shall neglect or refuse to pay the same within thirty days after notification from the treasurer, his name shall be stricken from the roll of members.

SEC. 5. All resignations shall be in writing. No resignation shall be accepted until all dues and other indebtedness shall be paid.

ARTICLE II.

MEETINGS.

SECTION 1. The stated meetings of the section shall be held on the first Tuesday of each month, at 8 P. M., except during the months of July and August.

SEC. 2. Special meetings may be called by the president, and shall be called at the written request of four members.

SEC. 3. A quorum for the transaction of business shall consist of seven members.

SEC. 4. At the stated meeting in November, nominations for officers shall be made, and at that in December an election shall take place for the following officers for the ensuing year:

President,
Two Vice-Presidents,
Secretary,
Treasurer,
Conservator.

The annual reports of the standing committees and officers shall be read at the December meeting.

ARTICLE III.

ORDER OF BUSINESS.

The order of business for stated meetings shall be as follows:

(1) Reading of minutes of last stated meeting and of subsequent special meetings.
(2) Reports of officers.
(3) Reports of standing committees.
(4) Reports of special committees.
(5) Nominations for membership.
(6) Unfinished business.
(7) New business.
(8) Communications and discussions.
(9) Adjournment.

ARTICLE IV.

DUES.

The annual dues of active, corresponding and associate members shall be one dollar, payable annually in advance, on the first of January of each year. Members elected after the first of October shall not be required to pay dues for that year. All members shall pay an initiation fee of one dollar.

ARTICLE V.

PROPERTY OF THE SECTION.

The conservator shall have charge of all apparatus, books, papers, models, specimens and other property of the section, except funds, and shall see that they are kept in order and readily accessible at the meetings of the section. Said property shall not be removed from the institute without the consent of the section.

ARTICLE VI.

FUNDS.

SECTION 1. No money shall be paid by the treasurer, except upon an order passed by the section and signed by the chairman of the meeting.

SEC. 2. Two auditors appointed by the president, shall, in conjunction with the treasurer, examine his accounts and render a report at the stated meeting in December.

ARTICLE VIII.

AMENDMENTS.

These by-laws may be temporarily suspended at any meeting of the section, by unanimous consent of the members present. Amendments of a more permanent character may be made at any stated meeting by a vote of two-thirds of the members present: *provided*, that such amendments shall have been presented in writing, and read before the section at a previous stated meeting.

List of Members

of the

Electrical Section.

of the

Franklin Institute, January, 1892.

A.

Archard, John W., ... Hersler El. Lt. Co., Gloucester.
Aldrich, Wm. S., ... Johns Hopkins University, Balto., Md.
Almon, Geo. H., ... Hotel Washington.
Arnold, Craig R., ... Chester, Pa.

B.

Bartol, H. W., ... 532, Drexel Building.
Bedell, C. H., ... 224 Carter Street.
Billberg, C. O. C., ... 3208 Race Street.
Bosley, Arthur L., ... Drexel Building.
Bullock, Wm. A., ... 528 Arch Street.

C.

Clark, Chauncey C., ... 925 Chestnut Street.
Clay, Harry G., ... 26 North Seventh Street.
Cleverly, Harry A., ... 1018 Chestnut Street.
Colvin, Frederick H., ... 3906 Fairmount Avenue.
Crew, Prof. Henry, ... Haverford College.
Currie, S. C. C., ... Drexel Building.

D.

Davids, Richard W., ... 308 Walnut Street.

E.

Edgerton, N. H., ... 146 South Sixth Street.
Eldridge, G. Morgan, ... 708 Walnut Street.
Emanuel, J. M., ... 1810 North Twelfth Street.

F.

Fearon, Charles, ... 3708 Walnut Street.
Freeman, S. E., ... 11th and Ridge Avenue.

G.

Gilpin, Richard W., ... 1332 Pine Street.
Graver, Erwin S., ... 2125 Venango Street.
Griggs, Dr. Wm. O., ... 509 Franklin Street.

H.

Hanks, Wm. F., ... 927 Chestnut Street.
Hering, Carl (Vice-President), . . . Room 31, 927 Chestnut Street.
Hering, Hermann S., ... Johns Hopkins University.
Higgins, H. Allen, ... Lansdowne, Pa.
Hoadley, Prof. Geo. A., ... Swarthmore, Pa.
Hockley, Thomas, ... 235 South 21st Street.
Hoskin, John, ... 308 Walnut Street.
Houston, Prof. Edwin J. (*President*), Central High School.

L.

Lacy, B. F., ... Central High School.
Levis, Minford, ... 1831 Spring Garden Street.
Lindsay, W. W., ... 2021 Mount Vernon Street.

M.

Marks, Prof. Wm. D., ... Edison Electric Light Company, Phila.
Marshall, Norman, ... Star Electric Company, 1320 Wallace St.
McClellan, Wm., ... 144 South Sixth Street, Reading, Pa.
McDevitt, Wm., ... 136 South Fourth Street.
Mitchell, Percy A., ... 1711 North Sixteenth Street.
Moore, A. F., ... 200 North Third Street.
Moore, James L., ... Moorestown, N. J.
Morris, Henry G., ... 926, Drexel Building.
Mucklé, M. R., Jr., ... 212, Drexel Building.

N.

Norris, Harry H., ... 1325 Vine Street.

P.

Paiste, H. G., ... 1201 Market Street.
Partridge, D. A., ... 1738 Sydenham Street.
Pemberton, Henry, Jr., ... 1947 Locust Street.
Pepper, David, Jr., ... 1827 Spruce Street.
Pfatischer, M., ... 224 Carter Street.
Pike, C. W. (*Vice-President*), ... University of Pennsylvania.

R.

Reese, Geo. C., ... Darby, Delaware County, Pa.
Reutlinger, Chas., ... 412 Dickinson Street.
Richardson, Chas., ... 918 Vine Street.
Rittenhouse, D. S., ... 1705 North Seventeenth Street.
Rondinella, Prof. L. F. (*Secretary and Treasurer*), ... Central Manual Training School.

S.

Salom, Pedro G., ... 926, Drexel Building.
Scott, E. Alexander, ... 2043 North Thirteenth Street.

Smith, T. Carpenter, ... 212, Drexel Building.
Spangler, Prof. H. W., ... University of Pennsylvania.
Stradling, Geo. H., ... Northeast Manual Training School.

W.

Wahl, Dr. Wm. H. (*Conservator*), . . 1436 North Thirteenth Street.
Whittingham, Alex. J., ... 1832 Reed Street.
Wiegand, S. Lloyd, ... 146 South Sixth Street.
Wilkins, A. W., ... 125 South Second Street.
Willyoung, E. G., ... 1010 Chestnut Street.
Winand, Paul A. M., ... 210 South Thirty-sixth Street.

Y.

Young, Wm. W., ... 2046 Park Avenue.

OFFICERS FOR 1892.

President, ... Prof. Edwin J. Houston.
Vice-Presidents, ... Mr. Carl Hering.
Mr. C. W. Pike.
Secretary,
Treasurer, ... Prof. L. F. Rondinella.
Conservator, ... Dr. Wm. H. Wahl.

PROCEEDINGS

OF THE

ELECTRICAL SECTION,

OF THE

FRANKLIN INSTITUTE.

[*Proceedings of the first stated meeting of the Electrical Section, held Tuesday, February 24, 1891.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, February 24, 1891.

Prof. EDWIN J. HOUSTON, in the chair.

The stated meeting of the Section was held this evening, at 8 o'clock.

There were present: Messrs. Billberg, Davids, C. Hering, H. Hering, Houston, Hoadley, McDevitt, Pemberton, Pike, Rondinella, Salom, Spangler, Wahl, Winand, and fifteen visitors.

The minutes of the special meeting for organization, held Saturday, January 31st, were read and approved.

The following communications were presented:

By Mr. Wm. McDevitt—On some dangers of electric lighting. Discussed by Messrs. C. Hering, Houston, Billberg, Salom, and the author.

By Mr. C. Hering—On a new standard cell. Discussed by Messrs. Hoadley, Perkins, Pike, Houston, H. Hering, and the author.

By Mr. C. W. Pike—On a new accumulator. Discussed by Messrs. C. Hering, Salom, and the author.

By Prof. H. Hering—On the effect of atmospheric pressure on batteries. Discussed by Messrs. Pemberton, Houston, C. Hering, Wahl, Spangler, Pike, and the author.

On motion of Prof. Rondinella, the remaining papers on the programme were postponed until the next stated meeting, in order to permit of the transaction of routine business.

The consideration of the by-laws, provisionally adopted at the special meeting of January 31st, was first taken up. The secretary read the regulations, which were thereupon considered section by section, and after suffering a number of amendments, were adopted as a whole.

Nominations for officers were then made, as follows:

For president—Prof. Edwin J. Houston.
" vice-presidents—Messrs. C. Hering and Pedro G. Salom.
" secretary—Prof. L. F. Rondinella.
" treasurer—Dr. Wm. H. Wahl.
conservator—Dr. Wm. H. Wahl.

The secretary *pro tem.*, was directed to cast the ballot of the meeting for the foregoing nominees, which accordingly was done, and the chairman *pro tem.*, declared them to be the officers of the section for the current year.

Mr. C. Hering moved a suspension of the rules, in order that the next stated meeting might be somewhat deferred. Carried.

The same member moved that the next stated meeting be held on Tuesday, March 10th. Carried.

The president thereupon named the following members to serve upon the committee on admission of members, viz: Messrs. C. Hering, H. Hering, Billberg, Pike, Salom, Rondinella and Wahl.

Adjourned. WM. H. WAHL, *Secretary pro tem.*

[*Proceedings of the stated meeting, held March 10, 1891.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 10, 1891.

Prof. EDWIN J. HOUSTON in the chair.

Present: Twenty-three members and visitors.

The minutes of the previous meeting were read and approved.

The treasurer reported that copies of the section's by-laws had been printed, and that the necessary stationery and supplies had been obtained for the secretary and treasurer.

The committee on admissions reported the following elections: To regular membership, Messrs. John Hoskin, T. Carpenter Smith, David Pepper, Jr., H. W. Bartol, F. J. Firth, Craig R Arnold, Fred'k H. Colvin and Alex. J. Whittingham; and to associate membership, Messrs. D. S. Rittenhouse, Wm. McClellan and H. Allen Higgins.

Mr. R. W. Davids presented a paper on "A new form of megohm resistance."

There was discussion upon this standard and others of the same type by Messrs. Pike, Wahl, Houston, C. Hering, and Billberg. (Referred for publication.)

Dr. Wm. H. Wahl gave "A *résumé* of recent developments in the manufacture of aluminium," in which he briefly traced the improvements of the past five or six years in both metallurgical and electro-chemical methods, and instituted a comparison between these two types of processes with the view of estimating the possibilities of each in the future cheapening of the cost of producing the metal. His remarks were illustrated by lantern slides of the principal methods of manufactures, and were discussed at some length.

There was also considerable discussion respecting the recommendation by a committee of the American association for the advancement of science of the word "alumin*um*" for the name of the metal, Prof. Houston speaking strongly in favor of the retention of the name "alumin*ium*," as being more in harmony with the nomenclature of the other metals, calcium, indium, magnesium, potassium, etc.

The meeting then adjourned. L. F. RONDINELLA, *Secretary.*

A NEW ACCUMULATOR PLATE.

BY C. W. PIKE,
Instructor in Electrical Engineering, University of Pennsylvania.

[*Read at the stated meeting of the Electrical Section, January 24, 1891.*]

While in Lowell, Mass., last year, a temporary craze upon the subject of storage batteries took almost complete possession of the town. The result of this was the production of several so-called new storage batteries. In reality, there was no attempt to produce a new type of accumulator, either by making use of new solutions or new metals. The sole novelty was in the form of the plates.

The inventors had but one object in view, namely, to construct a plate of such form that the active material would not be dislodged from the cavities in which it was held, even by a severe shock or jar. Weight troubled them little; high discharge rate and large capacity less; and efficiency not at all. In spite of this, the results obtained by two of the inventors, Messrs. Bradbury and Stone, were not bad.

Two forms of plate were devised by these gentlemen, of which the first is very curious in its construction. Each plate consists of a number of elements, and each element is made by bending two strips of lead into what most of the

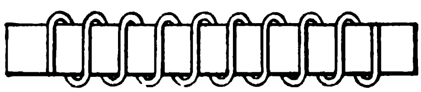


FIG. 1.

children, especially among the Germans, call a Jacob's ladder. (*Fig. 1.*)

This is then warmed and pulled in the direction of its length, taking care not to allow it to become twisted. When thus pulled out it has a number of interstices, into which active material can be placed. By placing several of these elements side by side and melting contiguous points together, a complete plate is formed, which is further strengthened by winding a lead strap around its perimeter,

and melting points of the plate to it. On looking at the completed plate, it will be seen that every interstice on one side of the plate is connected to another on the opposite side of the plate, so that the active material, when put on, will consist of plugs of the shape seen in *Fig. 2*, so that the plug, as a whole, could not by any ordinary means be dislodged.

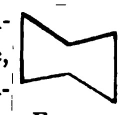


FIG. 2.

This form of plate has the advantage of large surface of

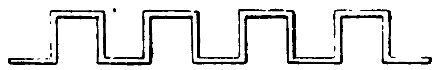


FIG. 3.

active material and a fairly large ratio of weight of active material to weight of supporting plate, but the cost of mak-

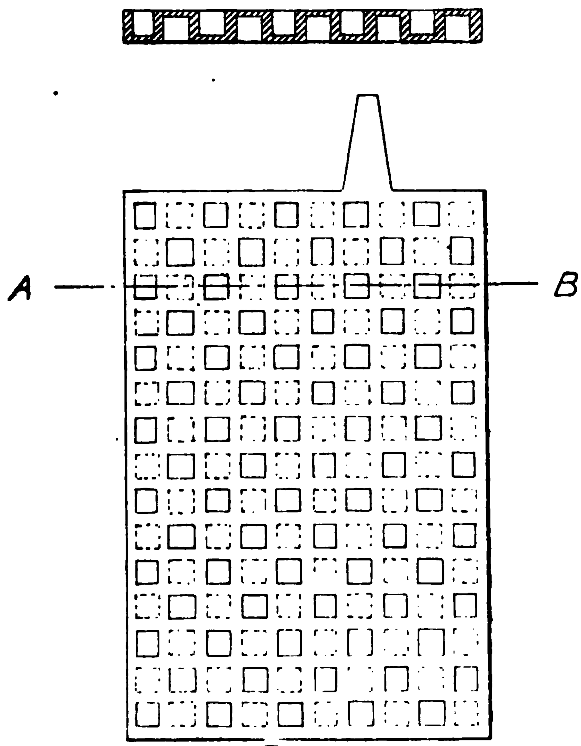


FIG. 4.

ing such a plate would more than overcome any advantages which it might have over ordinary forms of grid.

Realizing this, the inventors devised another form, made by bending lead strips over sticks of wood square in section, into the shape shown by *Fig.* 3. The first strip started from the top of the wooden stick, while the second strip started from the bottom of the stick; the third started from the top and the fourth from the bottom, and so on. The plate, when completed, looked on either side like a checker-board: lead forming the black squares and the uncovered portions of the wooden strips the white squares. The strips were then withdrawn and the plate strengthened, as in their first plate. This form of plate, though cheaper in construction than the former, was yet so costly; that they devised a mould, by which they were enabled to cast the plate entire. (*Fig.* 4.)

These plates before being filled are treated for a little while like a Planté, with a view to making the active material adhere strongly to the plate. The positives are then filled with red lead, and the negatives with litharge. The active material can be put into the plates in three ways:

(1) As a paste.

(2) As a powder, forced in under pressure.

(3) By pressing the oxides into sticks and driving these in.

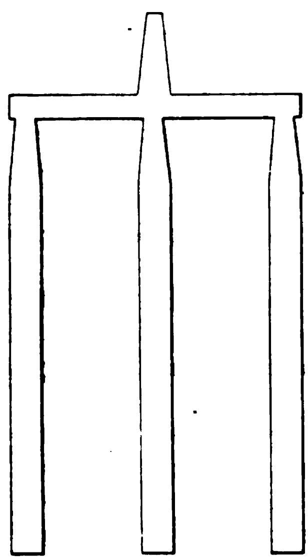


FIG. 5.

I have suggested another method, namely, casting the plates around these sticks, virtually using them for a part of the mould.

Each plate has a lug cast on its top, and the plates of similar polarity are connected together by a lead strip cast to these lugs. (*Fig.* 5.) On the top of this connecting strip is also a lug, of the shape of a truncated cone, which serves to connect one cell to the next by means of a connector, of the shape shown in *Fig.* 6. This device is extremely simple and convenient, but, like all

connectors, requires watchfulness in order to secure good contact.

On looking at this plate it seemed to me that it would accomplish very thoroughly the object for which it was designed, namely, to hold the active material in. Also that it would not buckle even when a very strong current was sent through it. Both of these opinions I have since found to be verified; the cells enduring an immense amount of jarring and short-circuiting without perceptible injury.

My impressions in regard to other points were less favorable. Of the total weight of a filled plate, but thirty-eight per cent. is active material; and of the total surface of the plate exposed to the electrolyte, but thirty per cent. is active material. Further, the plates are so thick that the inner portion of the active material will not be acted upon

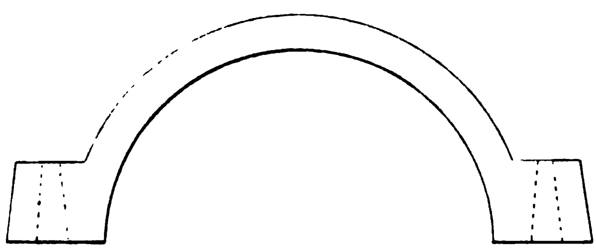


FIG. 6.

when the cell is rapidly discharged, since the outer portion which has changed from lead peroxide to lead sulphate prevents fresh sulphuric acid from permeating as far as the peroxide inside with sufficient rapidity to keep up the electro-motive force of the cell.

These considerations led me to believe that the internal resistance would be rather high, and its storage capacity and efficiency low, unless a low rate of charge and discharge was used.

Until recently the only tests made on this cell were by a gentleman in Sioux City, who obtained from cells, of which the dimensions were 5 x 8 x 8 inches, and the weight thirty-four pounds each, a storage capacity of 100 ampère-hours and a "quantity efficiency" of seventy-six per cent. with a charging and discharging current of about ten

ampères. The real efficiency, or the energy taken out divided by energy put in, was not stated by him.

The cell which I received from Messrs. Bradbury and Stone, was the *worst* which they had on hand, having been short-circuited for hours at a time, and having been allowed to stand with the solution partially evaporated. Consequently the plates were quite badly sulphated, and I did not have sufficient time to get them in first-class condition.

The instruments used were a Weston voltmeter reading to five volts and a Weston ammeter reading to twenty-five ampères. The test for resistance of the battery, made by the current and potential galvanometer method, gave, as was expected, a rather high result, varying from ·011 to ·016 ohms.

The next test was to ascertain whether it would give a current in excess of its normal current for any length of time. It was found that it would give twenty-five ampères for, at least, one hour. The next test was to determine the capacity and efficiency under different conditions.

The method of testing was as follows:

Discharge the cell at the desired rate till the P. D. was 1·8 volts. Immediately charge at the desired rate reading volts and ampères until charged. Note the duration of charge, and compute the ampère-hours $A\ H$ and the watt-hours $W\ H$. As soon as charged, immediately discharge at the desired rate, reading as before; and compute ampère-hours $A'\ H'$, and watt-hours $W'\ H'$.

$$\frac{A'\ H'}{A\ H} = \text{quantity efficiency}$$

and

$$\frac{W'\ H'}{W\ H} = \text{real efficiency}$$

under the conditions of the test.

The result of three tests is as follows:

Average charging current.	Average discharging current.	Ampére-hours taken out.	Quantity efficiency, per cent.	Real efficiency, per cent.
12·07	15·	65	61	51
11·2	11·2	56	77	65
10·02	10.03	75	75	66

They show, as with any cell, the gain in using low rates of charge and discharge; but beside this they show that this cell is very inefficient at a rate above ten ampères.

After the first test the cell was left open-circuited for twelve hours, after which twelve ampère-hours were taken out before the P. D. reached 1·8. After a further rest of three hours, six ampère-hours were taken out. This recovery, found in all cells, as was expected, is very much exaggerated in this cell on account of the thickness of the plates, and the cells would, in an installation where the work was intermittent, give results considerably better than is indicated by the table above. In all probability the capacity, efficiency and rate of discharge would be improved by making the plates thinner.

In the following table I have made a comparison of the different makes of cell as regards storage capacity, weight and volume. Not having weight and volume of the plates themselves at hand, I have been obliged to use the weight and dimensions of the entire cell. It will be seen that as regards the volume per ampère-hour, it compares favorably with the others, but in respect of ampère-hours per pound it is deficient.

	Ampère-hours per pound of cell.	*Cubic inches per ampère-hour.*
Accumulator,	2·86	4·44
Bradbury-Stone,	1·85	4·44
Detroit,	2·65	4·63
E. P. S. { Stationary,	1·91	7·06
E. P. S. { Traction,	2·26	5·53
Julien,	2·81	4·33
Pumpelly,	3·00	4·85

It is probable that a cell with this plate better designed and in better condition, would give results much more comparable to the others as regards efficiency, capacity and discharge rate, while it would surpass many of them in durability, and I hope at some future time to present to the section the results of some tests upon such a plate.

A NEW FORM OF MEGOHM RESISTANCE.

By Richard W. Davids.

[*Read at the meeting of the Electrical Section, held March 10, 1891.*]

The instrument of which this paper treats is not new entirely, but has been used for some years in England to a limited extent, so that the title refers mainly to its introduction in this country.

It is designed to take the place, at a small cost, of expensive and cumbersome wire resistances having approximately equal values, or the use of varying shunts, different electromotive forces and the wire resistances in ordinary use in measuring commercially the insulation resistance of cables, air lines, etc., by means of proportional deflections on a sensitive galvanometer. The resistance of these boxes varies from one to five megohms, although these limits are not necessary, so that they may be had of resistances approximating to those which are met in every-day use.

So far as it is known to the writer the construction is as follows: On an etched glass plate of some 4 x 6 inches a pencil line is drawn resembling a sinusoid; experience teaching to a small degree, however, its breadth and length. The pencil used is probably an ordinary lead, or rather graphite pencil, of a hardness found empirically to give the best results; this line is burnt into the plate most likely with the use of a flux; this operation must be done slowly, and takes some time. After a rough test for resistance to find if it is within the range sought, it is mounted in a block on springs to take up jars and make connection with the ordinary tall binding posts of apparatus needing high insulation.

There is no attempt made at adjusting these boxes: the plates are made and measured, any that are too high or too low being rejected, the surfaces being ground off and made over again. In this way a comparatively cheap instrument is obtained. They are not laboratory instruments, but designed

to meet the want of every-day line and cable testing, where speed and not great accuracy is desirable.

A somewhat similar instrument for laboratory work consists of a plate of unglazed porcelain, or even a sheet of paper, having pencil marks made on it; connection being made by means of springs resting on these marks. The objection found in these forms is that a breath of wind or jar may so change the contacts of the graphite particles as to seriously alter the resistance.

Some twenty of these boxes were brought to the writer for calibration, and the question arose as to the best way to measure them accurately and quickly. The first method tried was with a Thomson reflecting galvanometer, finding its constant with the one–ninety-ninth shunt, and sufficient resistance to give nearly the same deflection as with the meg and no shunt, using in both cases forty cells of chloride of silver battery.

As checks, other measurements were made using no shunts, and varying the electro-motive force; and also the bridge method. It is fortunate that there were two boxes of 100,000 ohms each at hand, as the second and third terms of the proportion, for with these calibrated in terms of a standard box which was the first term, it was possible to determine accurately the meg, the fourth term.

It was disappointing to find that the checks did not check, the figures obtained by the shunt method being much out. As the shunts were found to be practically correct, it could not be due to them, and on repeating the measurement with accumulators, the discrepancy disappeared, showing that the silver battery, even with small currents, polarizes. Everything seemed to go nicely now, perfect faith being reposed in the bridge method, when, in order to get a closer balance, the battery was considerably increased, with the disheartening result that it appeared that the resistance depended on the current used. This change was very small—less than one per cent.—and negligable in practice, but it seems to show that with such small currents as $\frac{1}{100000}$ of an ampère, appreciable change takes place, perhaps from heat, directly or indirectly.

It was an interesting point that the heat developed in such a box would raise one-sixteenth of a grain of water 1° C. in one minute. Supposing the resistance to be due to the imperfect contact of two adjacent molecules of carbon, the rise in temperature given could scarcely be enough to change the resistance.

It has been stated that change of temperature from 0° to 40° C. makes a difference of less than one per cent. in the value: also, that boxes made some years ago are practically the same now.

The use of the instrument was shown in one of the checks used. This was to find the comparative resistances of the various boxes by direct deflections, varying nothing but these with the megohms. With a very portable and accurate d'Arsonval galvanometer, the other boxes were checked rapidly; this was in effect measuring them, taking it for granted that any one was right.

In measurements on the street or in other places where it is difficult to set up and use an ordinary reflecting galvanometer, resistance boxes, different batteries, etc., all that would be necessary to get a very close measurement would be such a galvanometer, a suitable battery and such a megohm resistance.

A NOTE ON SOME DANGERS IN ELECTRIC LIGHTING.

By Wm McDevitt.

Inspector of the Philadelphia Board of Fire Underwriters.

[*Read at the stated meeting of the Electrical Section, held February 24, 1891.*]

After several years of experience in noting the dangers occurring in the use of electric lighting, it has been clearly demonstrated that in nearly every case the accidents resulted through ignorance both on the part of the workmen engaged in installing the wires and the lessee to whose care the new apparatus was entrusted.

These practical illustrations served as valuable lessons to those who witnessed them, more especially to the work-

men, whose education in the business consisted merely in following plans laid out by the contractor.

Although the introduction of electric lighting has rapidly increased in our city, its use has been comparatively free from accidents, proving that most of the inherent dangers have been controlled, leaving but few features that require the attention of inventive minds to overcome. The most important of the existing defects is that relating to fusible connections, as the innumerable variety of alloys used for fuse metal is very misleading and is still an element of danger. Some of these compositions possess the properties of good electrical conductivity and are slow to heat; other compositions are of a character exhibiting weakness when heated, resulting in annoyance from continuous breaks and offering temptations (as has been found) to use ordinary wire in the absence of proper fuses.

Another universal danger in electric lighting results from the want of some uniform or more ready method of perfecting splices or joints in conductors. Some workmen are in the habit of making loose copper unions, leaving the solidity of the joint dependent on solder, which, being a metallic cement, is liable to be fused by a possible heavy short-circuit occurring on the line, thus melting the solder and leaving a loose connection.

Probably the most alarming danger exists through the possibility of lightning being conducted into houses lighted by electricity where the latter is supplied by aërial wires. The existence of this danger has been demonstrated where the house wires are attached to gas fixtures, offering a ready path for the lightning, which, in leaping from the charged wires to the gas pipes, carries the electric light current across, forming an arc, which pierces the pipe, and where gas is present, it will be ignited, causing a steady blaze. If this accident should occur near the ceiling, the building would be endangered.

With the rapid introduction of new appliances in electrical science, it may reasonably be expected that the defects above-mentioned will be overcome in the near future.

PROCEEDINGS.

[*Proceedings of the stated meeting of the Electrical Section, held Tuesday, April 7, 1891.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, April 7, 1891.

Prof. EDWIN J. HOUSTON, President, in the chair.

Present, thirty-four members and visitors.

The minutes of the previous meeting were read and approved.

The treasurer presented bills for stationery, printing and clerical work, which were ordered paid when approved.

Twelve nominations to membership were referred to the committee on admissions.

At the request of the Secretary of the Institute, the subject of re-wiring the building in accordance with best modern practice, with a suggestion that detailed specifications, be prepared by the Section for that purpose, was presented and referred to a committee consisting of Messrs. Pike, Billberg and C. Hering, to consider and report.

Prof. C. Hanford Henderson presented a communication on "A Suggestion in Arc Lighting." The speaker called attention to the fact that progress in illumination has consisted in the substitution of continuous for reservoir systems. While the two essential factors, the source of heat and the substance to be made luminous, are combined in the candle, oil and gas as ordinarily used, they are separated in incandescent gas and electric lighting. In arc lighting the supply of energy is continuous, but the light-yielding substance, carbon, must be frequently replenished. The question as to whether arc lighting could be made continuous had therefore presented itself, and an experimental attempt was made to use gas issuing from hollow wrought-iron terminals, in place of the solid carbon. It was found that the gas and the arc formed two mutually repellent crescents of light; the terminals were fused and one of the gas jets was closed up. This negative result not being thought conclusive, the suggestion was brought before the Section in the hope of discussing the question as to whether the problem was sufficiently promising to merit further attention.

Prof. Houston stated in discussion that hollow carbon electrodes had been used at different times since 1852, fed by hydrocarbon oil, and by gas containing pulverized carbon, and the like, but without success, owing to the fusion of the terminals. As the intensity of the light varies with the sixth

power of the temperature, he considered a continuous arc impossible with our present refractory materials. There was further discussion by Messrs. Pike, C. Hering and Wahl.

Prof. L. F. Rondinella read a paper on "An Experimental Analogue for Direction of Induced Currents," which was discussed and referred for publication.

Prof. H. S. Hering gave the result of continued experiment on "The Effect of Atmospheric Pressure on Batteries," which seemed to show that the E. M. F. of standard cells did not become constant until about two hours after setting up. This result elicited considerable discussion.

Upon motion of Mr. C Hering, the treasurer was instructed to purchase a letter-box for the reception of queries on electrical subjects, which would be periodically submitted to the Section.

The meeting then adjourned. L. F. RONDINELLA, *Secretary.*

AN EXPERIMENTAL ANALOGUE FOR DIRECTION OF INDUCED CURRENTS.

BY L. F. RONDINELLA, M.E.
Prof. of Drawing, Central Manual Training School.

[*Read at the stated meeting of the Electrical Section, April 7, 1891.*]

The striking analogies which exist between current electricity and magnetism, form an important aid in acquiring a clear understanding of the fundamental principles of modern electrical science. For example, an electric current is assumed to pass through a generator from its south to its north pole, and from thence through an external circuit back to the south pole again. So, also, are magnetic "currents," or lines of force assumed to pass through and outside of a magnet.

In an induced electric current lines of force are made to flow around a conductor in a right-handed or clockwise direction when the observer is looking along the conductor in the direction of the current, or toward the south pole of the generator. Similarly, in an induced- or electro-magnet, an electric current is made to flow around the core of the magnet right-handed when the observer is looking in the direction of the lines of force in the core, or toward the south pole of the magnet.

The directions of lines of force are usually discovered by

the effect produced upon a small permanent magnet or magnetic needle, which will always come to rest with it, north pole pointing in the direction in which they flow through it. Then since the direction of a current depends upon the direction in which the lines of force flow round it, the former also is discovered by noticing the way in which the needle is deflected by the latter.

As there are two directions in which the current may flow through the conductor, and two positions in which the needle may be placed relative to it (above or below), it has been found necessary to use some *memoria technica* to quickly

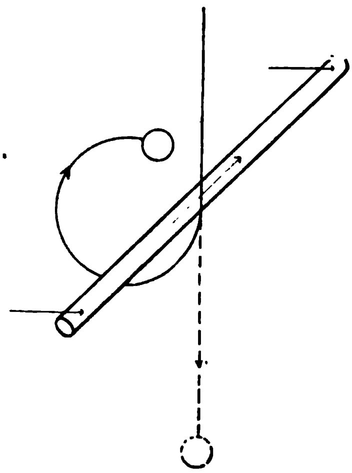


FIG. 1.

determine the direction of the current, from the way in which it deflects a needle; and among several devices that have been proposed, the following are most used, although they all present certain difficulties.

Ampère's rule is to imagine an observer swimming with the current in a conductor, with his face always toward the north pole of the needle, which will then be deflected toward his left hand. The disadvantages of this rule are the difficulty of imagining the direction of the observer's left hand when he is placed in unusual positions, and the fact that it was intended for determining the deflection of the needle from the direction of the current which it pre-

supposes to be known, and it must therefore be used inversely for our purpose.

Another device is to remember the fact that when a current flows from South to North Over a needle, its north pole points West, by noticing that the direction initials spell the word SNOW; and similarly a third rule impresses the statement that when a current flows from North Over a needle to South its north pole point East, by spelling the word NOSE with the direction initials. A vital point that seems to be most troublesome to remember in these, is whether the current is over the needle or *vice-versa*, and the difficulty of always finding a part of the conductor running north and south interferes with their direct application.

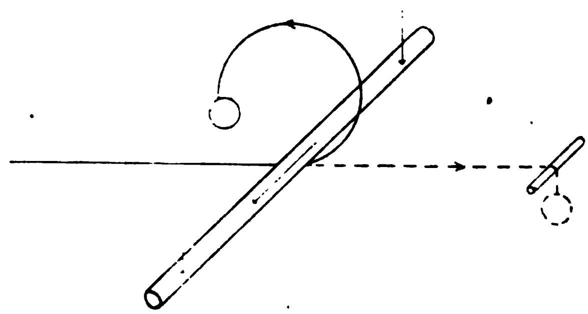


FIG. 2.

None of these devices can be used to predict the direction of the current that will be induced in a conductor when it is moved in a certain direction through a known magnetic field, and for this purpose the only one familiar to the writer is to use the right hand with (*a*) the thumb, (*b*) the first and (*c*) the second finger pointed outward in the three rectangular directions to represent respectively (*a*) the direction in which the conductor is moved, (*b*) the direction of the lines of force, and (*c*) the direction of the induced current. The trouble in applying this is to remember which hand to use and what each finger represents.

As an addition to these, and as an analogy that is not liable to confusion, the following experiment is suggested: If a small weight be suspended at the end of a piece of string (*Fig.* 1), the force of the weight acts downward

in the direction of the string, and the latter may be used to represent a "line of force" acting vertically downward. If then a horizontal rod, which may be used to represent a "conductor," be moved from left to right so as to strike sharply against the string a short distance above the weight, the latter with its "line of force" will revolve around the rod or "conductor" right-handed—a correct analogy to the phenomenon of electric induction. To represent lines of force acting horizontally in either direction, or vertically upward, the string may be held opposite or below a rod over which it is passed (*Fig. 2*), the force of the weight on its end acting along it in the proper direction. The rod may then be moved as desired, and the resulting revolution of the weight and string will remain a correct analogy for electric induction under similar circumstances. Then knowing the direction of the lines of force around the conductor in any case, the direction of the induced current flowing through it is readily determined by remembering that the observer is looking in the direction of the current when the lines of force flow right-handed around the conductor.

A NEW FORM OF STANDARD CELL.

BY CARL HERING.

[*Read at the stated meeting of the Electrical Section, held Feb. 24, 1891.*]

The standard cells used at present may be said to be limited to the Clark cell and the Daniell cell. Each one of these has its specific advantages and disadvantages. The Clark cell is always ready for use, but is difficult to make, is affected by temperature, and has the important disadvantage that if by accident it is short-circuited it polarizes so rapidly and so much, that it is of no use at all until it has been allowed to rest and recuperate for some time. Such accidental short circuits are not unlikely to occur, and they may furthermore occur, by the crossing of two wires, for instance, without the knowledge of the operator, thus making it possible that the

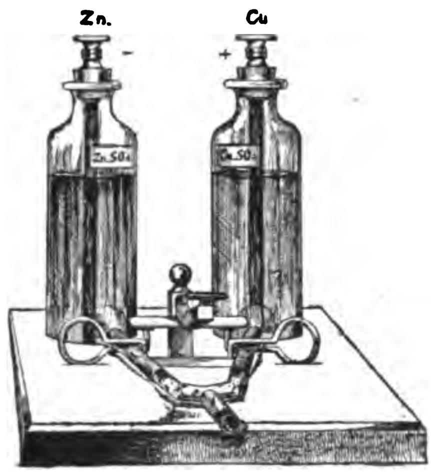
measurements made with it are incorrect. The Daniell cell, on the other hand, does not polarize at all, it may be short-circuited and used almost immediately afterwards; furthermore, it is very easy for any one to construct a Daniell, and it is practically independent of temperature. But it has the important disadvantage that it must be freshly set up just before using and cannot be kept standing. In their good and bad qualities, therefore, the two cells are diametrically different.

The object of the present form of cell is to try to combine all these good points in one and the same cell. As the polarization of the Clark cell is an inherent fault and cannot be remedied, there remains only to endeavor to devise a form of Daniell which is always ready for use. The difficulty is due to the fact that there are two liquids which must be in contact with each other; these liquids, will tend to mix, and if they mix to the slightest extent only, the cell can no longer be used as a standard. The difficulty therefore resolves itself to a means for enabling two liquids to be in contact without mixing. Numerous forms of Daniell cells have been devised with this object, but they accomplish it only in a degree, as for instance, by capillary tubes, porous diaphragms, etc., all of which, however, do not prevent mixing, but merely diminish the rapidity of the mixing.

In a number of these forms, in which two bottles or reservoirs are connected together by a tube, the mixing takes place quite rapidly unless the pressure of the liquid is exactly the same in both bottles, a condition not always easily complied with.

Some time ago the writer had occasion to use a cell of this form devised by Prof. Barker, which consisted of two bottles containing the two liquids with their respective electrodes, the bottles being connected at their bottom by a small tube with a stopcock. This cock was opened only during the moment when the cell was being used. But even during a few seconds no small amount of mixing took place, especially if the pressure was different in the two bottles. It is very difficult to avoid the latter, owing to the different specific gravities of the liquids and their different

heights in the two bottles. The writer therefore modified this form by inserting two stopcocks in this tube and allowing the portion of the tube between the two cocks to communicate directly with the air, as shown in the adjoining cut. By this means the liquids, which mix at their contact, are allowed to drain off as rapidly as they mix. As there is an outward flow of the liquids through the cocks, the mixed liquids cannot pass back into the bottles. The liquids in contact with the electrodes will therefore always remain pure. To prevent too rapid a flow, which would needlessly waste the liquids, some filter paper, cotton or asbestos is packed into the tubes. The intermediate tube may be



drained completely, there is always a film of liquid sufficient to answer for a contact if the cell is used on open circuit, which is the only way any standard cell should be used. It was even found that the film of liquid through the cocks when closed, was sufficient to give an electro-motive force which, however, falls as soon as the slightest current is allowed to flow.

The internal resistance of such a cell is naturally quite high, from 10,000 to 20,000 ohms, but this is no disadvantage for the usual class of open-circuit testing.

The e. m. f. of a Daniell cell, according to a report of Dr. Fleming, is as follows: when the specific gravity of the zinc

solution is 1·2, and that of the copper is 1·2, when the zinc is amalgamated, and the copper is freshly electroplated with an untarnished, salmon-colored coating, having no brown spots, the e. m. f. is 1·105 true volts at about 16° C. The temperature correction is negligable. The solutions and metals must be perfectly pure, and the solutions made with distilled water and filtered, being diluted to the required amount after filtration.

Such a cell may be kept standing indefinitely, and is always ready for use. The only remaining objection is that the copper electrode does not remain clean. It should be freshly electroplated, before using, which is readily done in a test tube with a platinum anode. To overcome this, the writer suggests to amalgamate the copper, and when not in use to keep it in a tube of mercury. Whether this introduces other objections has not yet been tested.

Another modification suggested is to place in the bottom of the bottle containing the zinc solution, a quantity of pure zinc scrap, not in contact with the electrode. Similarly, copper scrap in the other bottle. Should any mixture of the liquids take place, they will be freed of their impurities by these metals, which, not being in contact with the electrodes, will not affect the e. m. f.

In experimenting with this cell a curious phenomenon was noticed which does not appear to be known. It was found that the slight pressure produced in the bottles by inserting the corks at the top, produced decided differences in the e. m. f. of the cell; this was noticed for each of the liquids, and was different in the two cases. It was therefore found essential to use a cork with a hole through it, so as to prevent this pressure from being exerted. The effect of this pressure has since been investigated by a very extended and interesting set of experiments made by Prof. Hermann Hering, and will form the subject of a paper to be read by him following this one.

PROCEEDINGS.

[*Proceedings of the stated meeting of the Electrical Section, held Tuesday, May 5, 1891.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 5, 1891.

Prof. EDWIN J. HOUSTON, President, in the chair.

Present, forty-eight members and visitors.

The minutes of the previous meeting were read and approved.

The treasurer presented bills for printing and clerical work, which were ordered paid when approved.

The committee on admissions reported four regular and ten associate members elected since last meeting.

The committee appointed to consider the subject of re-wiring the Institute building, presented a report suggesting certain changes in the present wiring, and stating the cost at which they could be made. The report was accepted and referred to the board of managers.

Three nominations to membership were referred to the committee on admissions.

Mr. David Brooks presented a communication on "The Value of Oil as an Insulator for High Voltage Currents," illustrated with some brilliant experiments. It was referred for publication.

Prof. Henry Crew gave a description of "Ewing's Theory of Induced Magnetism," illustrated with a model made after his suggestions, and with charts of typical magnetic phenomena that may be explained on this hypothesis. The communication was discussed by Prof. Houston and Mr. Pike, and referred for publication.

Mr. John Hoskin read a paper on "A rough-and-ready Dynamometer." Referred for publication.

There was considerable discussion on the contents of the Question-Box.

The meeting then adjourned. L. F. RONDINELLA, *Secretary.*

A ROUGH-AND-READY DYNAMOMETER FOR SMALL MOTORS.

BY JOHN HOSKIN.

[*Read at the meeting of the Electrical Section, held May 5, 1891.*]

I have been requested to bring to your notice this evening a friction-brake dynamometer that is by no means new, but is one that is deserving of being more widely known by electricians than appears to be the case.

Like the well-known Prony brake it acts as an absorption dynamometer; and without detracting from the acknowledged value of this instrument, especially for testing the value of large prime-movers, yet we need something more portable, more convenient to use, in the very numerous cases where it is desirable to test the efficiency of small motors.

We need a rough-and-ready instrument that is portable, inexpensive, readily used, and at the same time reliable.

This we find in a friction-brake dynamometer, one of the many modifications of those illustrated by Mr. William Worby Beaumont, in his paper on friction-brake dynamometers, read before the Institution of Civil Engineers in London, November 13, 1888, and published in 1889 in the *Proceedings* of the Institution.

Its construction requires only the use of a leather belt with a spring balance attached to one end, and a suitable weight at the other. The belt is to be thrown over the belt pulley of the motor, the spring balance is fastened to the floor base, or support of the motor to be tested, and the weighted end hangs pendant on the side of the pulley which, when in motion, will tend to lift the weight. When the motor is at rest, the strain of the weight should be read off on the spring balance. This reading we will call W. When the current is switched on and the motor runs at speed, the spring balance should again be read off, since the friction of the pulley on the belt will have a tendency to raise the weight; this reading we will call W'. The difference

between W and W' in pounds, multiplied by the circumference of the pulley in feet (including one-half the belt thickness on each side), and this by the number of pulley revolutions per minute will give the foot-pounds of mechanical energy, which can be compared with the electrical energy required to produce it, in the usual manner.

Thus, in a few minutes with the aid of a speed counter or tachometer, a voltmeter and an ammeter, the efficiency of a motor can be determined, and its ability to do a desired amount of work ascertained at once, instead of being left to guess-work, as would often be the case if more bulky or elaborate apparatus were needed.

It should not be imagined from these remarks that this form of dynamometer is applicable to small motors only; but it is evident that for testing larger machines where many horse-power have to be measured, the apparatus needs more elaboration, especially in the use of friction blocks under the belt or pulley strap, their lubrication, and the use of a dash-pot to steady the brake when the motive-power is irregular.

But I need not enlarge on this, except to say that in these particulars, whether using steel strap, or leather belt with friction blocks, or rope friction, the same care is needed as in the Prony brake to obtain correct readings.

Before concluding, I submit to your consideration the value of the Waldron rotary pump for use as a dynamometer, although I have never heard that it has been applied to that purpose. In examining one of these engines recently for other purposes it occurred to me that it would serve as an excellent dynamometer.

This pump is operated by rotary piston blades working in a chamber, without leakage, and with but small friction, the amount of which can readily be ascertained and calculated for use as a "constant." Its capacity per revolution, and the number of revolutions being known, as also the pressure against which it works, which can be regulated by a pressure gauge, the foot-pounds of work are at once arrived at.

This method of measurement will correctly register the

work done, although the speed may be irregular; and its results can be made more accurate than that of the friction dynamometer, because not subject to the irregularities arising from differences in lubricants, temperature, etc., which makes it necessary to use adjusting screws in most forms of friction-brake dynamometers.

THE VALUE OF OIL AS AN INSULATOR FOR HIGH VOLTAGE CURRENTS.

BY DAVID BROOKS.

[*Read before the Electrical Section, May 5, 1891.*]

Even as late as 1884, in the electrical works, oils were placed among conductors. For instance, James T. Sprague, in the second edition of his book, places them among conductors "in the order of their specific gravity." His first patent for the use of oil as an insulator was taken out in 1878, and now the matter is receiving great attention among the electricians of Europe. In the *London Electrical Review* there is an account of tests by Siemens and Halske, of Berlin, in which they state that an ordinary Siemens electric light cable was inserted, and broke down at a pressure of some 15,000 volts, but when oil was used, it perfectly withstood the pressure as high as 20,000 volts.

Oil has been used in Switzerland with complete success not only for insulating wires, but also for transformers.

The writer has made the following experiment to show how much better oil is than the air for insulation. A large Holtz machine that sparked 7·5 inches through the air was unable to puncture the insulation of a cable of twisted wires separated one-fourth of an inch, when immersed in oil.

The ends of the twisted wires, were spliced to rubber-covered wires, and these were attached to the poles of the Holtz machine, after glass tubes had been drawn over them. The twisted wires were then placed in a jar contain-

ing oil with a layer of water floating on it, the oil being heavier than the water.

The spark broke through the tubes from wire to wire above the oil; the part of the jar containing water the tubes were broken opposite the splice, while the twisted wires in the oil stood the entire pressure of the machine, 7·5 inches spark. Such a spark would be equivalent to 175,000 volts, as defined by Warren De La Rue, between a point and a disk, but this spark of 7·5 inches was between two spheres which requires a much higher voltage.

When no glass tubes were used to protect the conductors, the voltage or tension was much reduced by silent or brush discharge, blue sparks passing through the rubber covering. When bare wires were used to connect the two poles of the Holtz machine, still less tension was produced on account of leakage through the air.

The experiment tends to show that the air is not a good insulator for very high voltages, and also to confirm the experiments made in Switzerland as to the value of oil for insulating transformers, and protecting them from destruction by lightning.

Experiments have also been made with heavily insulated electric light cables for conveying high voltages. None of them stood a tension above 12,000 volts, and most of them broke down by the use of less than 10,000 volts.

PROCEEDINGS.

[*Proceedings of the stated meeting of the Electrical Section, held Tuesday, June 2, 1891.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 2, 1891.

Prof. EDWIN J. HOUSTON, President, in the chair.

Present, twenty-six members and visitors.

The minutes of the previous meeting were read and approved.

The treasurer presented bills for printing and clerical work, which were ordered paid when approved.

Four nominations to membership were referred to the committee on admissions. This committee reported three elections since last meeting.

The secretary announced the death of Mr. David Brooks, active member, and upon motion a committee consisting of Messrs. C. Hering, Arnold and Wahl was appointed to draft suitable resolutions, and report them to the Institute as the action of the Section.

Mr. G. H. Almon read a paper on "Lightning Arresters." Referred for publication.

Prof. H. S. Hering concluded the results of his experiments on "The Effect of Atmospheric Pressure on Batteries." This and his former communications on the same subject were referred for publication.

Dr. Wm. H. Wahl exhibited and described an incandescent gas lamp, invented by Mr. Lungren.

There was discussion on this and similar lights by Profs. Houston and Rondinella and Mr. Billberg.

Mr. C. Billberg described a new time switch for electric motors, and exhibited a model in operation.

Mr. Carl Hering exhibited and explained a portable photometer for measuring illumination as well as candle-power.

The Question-Box contained queries concerning the magnetic polarity of drills, the deterioration of copper wire from a long-continued current of electricity, and the proper rise of temperature to allow in a well-designed dynamo. These elicited much interesting discussion.

The meeting then adjourned.

L. F. RONDINELLA, *Secretary.*

DAVID BROOKS.

[At the stated meeting of the Institute, held Wednesday, June 17, 1891, the Secretary presented the following memorial of the late David Brooks, prepared by a special Committee of the Electrical Section. The meeting thereupon approved the memorial, and directed its reference to the Committee on Publications.]

David Brooks, one of the most widely-known electricians of the day, one of the early telegraphers, and for many years an active and useful member of the Franklin Institute, died May 31, 1891, at Germantown, in this city.

Mr. Brooks was born in Brooksvale, Conn., January 26, 1820, and traced his descent directly from Henry Brooks, who emigrated with his family from Cheshire, England, in 1640, and settled in Cheshire, Conn., so named by his children from their native town, and there, and in the portion of the town known as Brooksvale, which bears the family name, the family is still represented.

The name of David Brooks is perhaps more intimately associated with the development and improvement of telegraphic communication than that of any other electrician of America, save Morse, his professional association with this epoch-making branch of electrical engineering dating back to the very beginning of telegraphy in the United States, and continuing actively down to the time of his lamented death.

The principal incidents of his professional career are briefly stated in the following:

After leaving college, at the age of twenty, he became instructor in mathematics, in the United States Navy. In 1845 he left the service and began that association with telegraphy which continued throughout his long and active career.

His first engagement in the telegraphic field was in conjunction with Mr. James D. Reid, to put in service the tele-

graph line between Lancaster and Harrisburg, in this state, which is claimed to have been the first commercial line constructed and operated in the United States, after the successful demonstration of Prof. Morse on his experimental telegraph line between Washington and Baltimore. In the following year, he superintended the construction of the line across the Alleghenies between Pittsburgh and Philadelphia, for the Atlantic and Ohio Telegraph Company. In 1847 he is credited with the invention of the earliest repeating instrument, known as the "Button Repeater," which was used with success.

In 1850 Mr. Brooks was appointed by the United States Court to prepare an opinion as an expert upon the Morse and the Bain systems of telegraphy, which opinion was frequently cited in the course of the litigation that followed.

In 1851, Mr. Brooks was engaged with construction of the first telegraph line in Mexico, between Vera Cruz and the City of Mexico. Upon his return to the States in 1852, he was engaged by the Pennsylvania Railroad Company, as the superintendent of the company's telegraph lines between Philadelphia and Pittsburgh.

In 1854 he became superintendent and manager of the Atlantic and Ohio Telegraph Company. This position he held until 1862, when the company was absorbed by the Western Union Company. He held the position of district superintendent at Philadelphia, with the company, until 1857, when he resigned.

Since then and until his death, he devoted his energies to the development of a number of inventions for the improvement of the telegraph service, which have made his name well known throughout the world.

In 1873 he was named by President Grant as one of the Commissioners of the United States to the Vienna International Exposition, to report upon telegraphic instruments. His report appears in the official publications of the Government on the exhibition, and constitutes one of the most useful and practical contributions of the series.

The most important of Mr. Brooks' inventions relate to the subject of insulation. He was the first to appreciate

and to apply the now universally acknowledged superiority of paraffine for this purpose; and his paraffine insulator for telegraph lines has been widely introduced throughout the United States and in Europe.

He was also among the first to appreciate and to advocate the system of underground lines for telegraph and other electric wires, and his application of the high insulating qualities of the mineral oils, and other liquid insulators for such lines has proved highly successful. The latest improvement in his liquid insulation for underground lines was the substitution of heavy rosin oil for paraffine oil used before. The results were exceedingly encouraging.

Mr. Brooks' services to electric science were recognized early in his professional career by his election to membership in a number of prominent scientific societies at home and abroad. He was elected a member of the Franklin Institute in the year 1867, and was actively interested in the work of the Institute almost to the day of his death.

He was especially interested in the Electrical Section, of which he was one of the founders, and the last technical contribution of his life was made at the Section's stated meeting in May last, when he read a paper "On the Insulating Properties of Oils," which appears in the June impression of the *Journal.*

Personally, Mr. Brooks was a man of great amiability of character, and of commanding presence. By his death the Institute has lost one of its most active and distinguished members, and the world of science one whose inventions have contributed in no small measure to advance the art of telegraphy to its present state.

CARL HERING, *Chairman.*
CRAIG ARNOLD,
WM. H. WAHL,
Committee of the Electrical Section.

EWING'S THEORY OF INDUCED MAGNETISM.

BY PROF. HENRY CREW.

[*Read at the meeting of the Electrical Section, held May 5, 1891.*]

The labors of Rowland, Stoletow, Wiedemann and Ewing have brought to light so large a number of magnetic phenomena that any general principle on which they may be explained would receive a warm welcome at the hands of all interested in this rapidly growing subject.

Any generalization of this kind would be called upon to explain the following phenomena, which are selected each as typical of a large *class* of well-known facts.

(I) *The behavior of a piece of iron when placed in a magnetic field whose strength is made to pass through a cycle of changes.*

(*a*) For magnetizing forces ranging from $\frac{1}{50000}$ to $\frac{1}{25}$ of a C. G. S. unit, the intensity of magnetization is proportional to the magnetizing force (Rayleigh, *Phil. Mag.*, March, 1887).

(*b*) For a range of magnetic forces extending (roughly) from $\frac{1}{25}$ to 5 C. G. S. units the magnetization increases with a rapidity enormously greater than the strength of field.

(*c*) From this point on, as the force continues to increase

the permeability decreases and the induction approaches a limit which, the work of Ewing and Low (*Phil. Trans.*, 1889), leads us to think, has for a value about 40,000.

(*d*) If now the magnetizing force be diminished, the magnetization diminishes, ***but not so rapidly***, until, when all the force is withdrawn, there still remains a perfectly definite magnetization, which is used as a measure of the "retentiveness" of the iron under the conditions of the experiment.

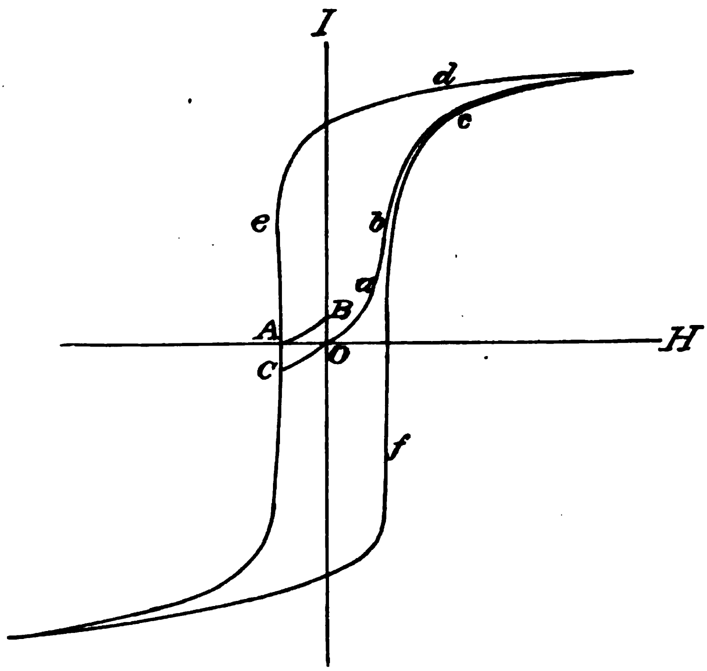


FIG. 1.

(*e*) If next the magnetizing force be reversed the magnetization will rapidly diminish, and at a certain negative value of the magnetizing force, the magnetization of the iron will presently reach a zero value; but, if the current be broken the magnetization will "spring back" along the line *A B* (*Fig. 1*).

In order to destroy the magnetization of the iron we must pursue our way along the curve to a point at *C*, such that when the current is withdrawn and the magnetization

falls, it will fall along the line *C O*, from *C* to *O*. The iron here, however, will have magnetic properties quite different from those which it had before magnetization.

(*f*) Having reached a large negative value we obtain, on gradually diminishing the force and allowing it to increase in the opposite direction, a curve corresponding to (*e*) and (*d*), and nearly symmetrical on the other side of the axes of *I* and *H*.

The curve *a, b; c, d, e, f* is a graphical summary of the now well-known facts of hysteresis.

(II) *Nearly all reversals of sign in the change of the magnetizing force are accompanied by small changes in the magnetization.*

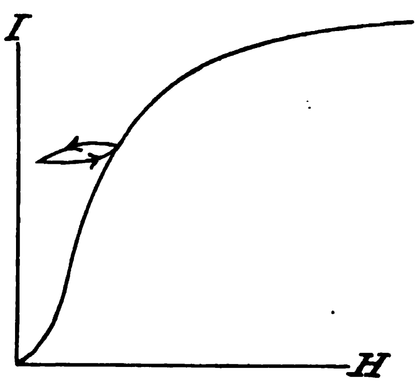


FIG. 2.—Illustrating the effect of a small superimposed cycle in the magnetizing force.

In the magnetization curve any reversal starts out along a nearly horizontal line. (*See Fig. 2.*)

(III) *The fact that a piece of iron submitted to vibrations or mechanical shocks is magnetized and demagnetized more readily and with a smaller hysteresial area than if it remains undisturbed.* The *I H* curve then takes a form of which *Fig. 3* is a type.

(IV) *The phenomena of "time lag" in magnetization.* Ewing finds his magnetometer needle creeping up long after the time when Foucault currents or self-induction could have any effect.

Rayleigh (*Phil. Mag.*, March, 1887) finds that with a second coil he can balance the effect of a magnetizing coil and iron core, at the end of any given time, say five seconds.

If balance is obtained at the moment of making the magnetizing current, then at the end of five seconds there will be a deflection of the magnetometer in *one* direction. But if the balancing coil is so arranged as to give balance at the end of 5 seconds, then there will be an *initial* deflection in the *other* direction.

(V) *Phenomena of stress and magnetism.* These are usually grouped under two heads, viz:

(*a*) Those which occur when a body has first been placed in magnetic field and the stress then made to vary.

(*b*) Those which occur when a body is first placed under a constant stress and the magnetizing force is made to vary.

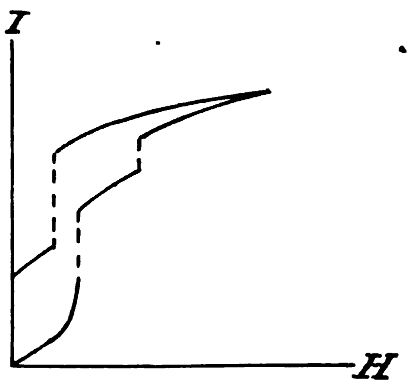


FIG. 3.—Illustrating the effect of tapping on the $I\ H$ curve.

The hysteresis between magnetization and stress may be best illustrated by the curve in *Fig. 4*, derived by Ewing (*Phil. Trans.*, 1885) from experiments on a piece of iron which had been previously strained.

If, however, the wire be a freshly annealed and unstretched one, then the hysteresis is much larger, and we obtain a curve like that in *Fig. 5*, the maximum on the down curve corresponding to a negative load, *i. e.*, to a pressure.

The effect of a *constant* load on the $I\ H$ curve may be seen in *Fig. 6.*

From this it will be seen that longitudinal stress aids magnetization at first, but for larger values of H it diminishes it.

(VI) *Effects of heat on magnetization.* In general, perma-

nent magnetism is decreased by heating through any cycle of temperatures. But in the case of induced magnetism we must distinguish between two cases:

(*a*) When the heating is not high the effect is to increase the susceptibility.

(*b*) When the heating is excessive, it decreases the susceptibility.

The foregoing are a few of the hundreds of facts which experiment has recently brought to light. Any tolerably complete explanation of them must include two parts, viz:

(*a*) An explanation of the ampèrian currents (or of molecular magnets on some other hypothesis.)

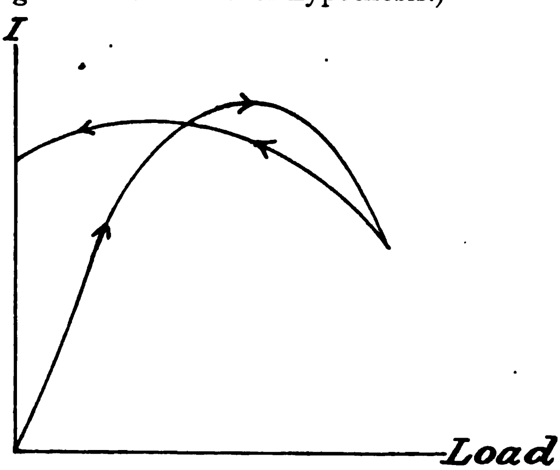


FIG. 4.—Effect of loading an already strained iron wire in a magnetic field.

(*b*) The *arrangement* of Weber's molecular magnets in the mass.

We are here concerned only with the second and apparently less difficult part of the problem.

The first attempt at a theory of magnetic induction is that of Weber, who supposes the molecules of freshly annealed iron to be turned at random in all directions, and to be held in their respective positions by constant forces acting along their respective axes. This hypothesis explains the existence of an upper limit to magnetization; it also explains the experiment of Beetz, in which he obtains a strong magnet by the electrolytic deposition of iron in a

magnetic field; but is condemned by its failure to explain the phenomenon of permanent magnetism.

Maxwell, therefore, modifies Weber's theory by supposing that when the axis of a magnetic molecule is displaced through an angle greater than a certain limiting angle it receives a certain set. Thus amended, the hypothesis of Weber covers a much larger number of facts, *e. g.*, permanent magnetism, and the production of permanent magnetism by moderately high forces only. Maxwell's theory fails, however, to explain such a phenomenon as that of "time lag," which has been so elegantly worked out by Rayleigh and Ewing (*Roy. Soc. Proc.*, June, 1889).

In the *Philosophical Magazine* for September, 1890, Prof. Ewing offers the apparently bold hypothesis of no constraint

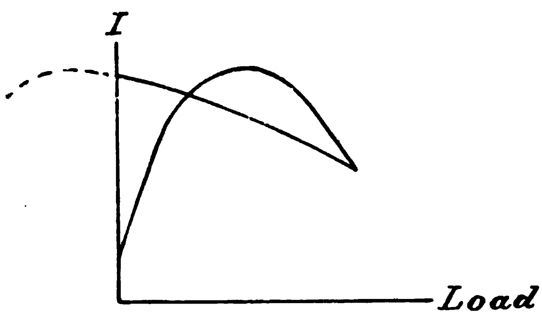


FIG. 5 —Effect of loading a fresh'y annealed iron wire in a magnetic fie'd.

at all acting on the molecular magnets, save only their magnetic action on one another.

A large model, constructed on the lines suggested in the paper just mentioned, was here exhibited to the Section.

A helix, about three feet long and one foot in diameter, contained within it three tiers of magnets mounted on three glass decks. Each magnet was balanced on a needle-point, the whole arrangement showing in a striking manner the interaction of the magnets and the multitude of different positions of equilibrium which they may assume.

The sufficiency of this hypothesis may best be tested by applying it to explanations of the six typical facts just mentioned.

(I) Stirring the magnets up, with no current in the helix,

we observe that they arrange themselves very much at random, yet more of them pointing north than in any other direction. (The north poles were fitted with damping vanes.) This, of course, represents the magnetization of iron by the earth's field.

Balancing the earth's field by a slight current through the helix, and again stirring up the magnets, we have a piece of freshly annealed iron, with practically no external moment to start with.

A slight increment of current deviates the magnets to some extent, thus giving an external moment, but no new position of equilibrium is assumed, so that on bringing the current back to its initial value, we find the iron without any residual magnetism, which corresponds exactly to the fact of nature.

Increasing the current a little more, one observes a stray magnet now and then passing into a new position of equilibrium which corresponds to the part *a* of the curve in *Fig. 1*.

A little more current and these changes occur in a more wholesale manner, giving the part *b* of *Fig. 1*.

Increasing the strength of field to about two C. G. S. units, we find that all of the magnets have set themselves nearly in the direction of the field, an arrangement which corresponds to the asymptotic part of the *I H* curve.

Diminishing the magnetizing force by gradual steps to zero there remains considerable external moments, which, however, is destroyed and generally reversed by a comparatively small negative force.

In fact, the cyclic curve thus obtained bears a striking resemblance to those actually obtained from a piece of iron. In the *Electrical World*, May 16, 1891, Mr. Arthur Hoopes has three curves, taken from this model under different conditions.

(II) If for any given value of magnetizing field we reverse the sign of change in the current, the magnets will be observed to change direction very slightly, falling back into their nearest position of equilibrium, where they are held by each other until subjected to a change of more con-

siderable size. This, of course, is the second phenomenon mentioned above.

(III) One has only to shake the model, even slightly, to see the effect of tapping a piece of soft iron during magnetization or demagnetization. If the magnets be not very close together, it takes careful handling not to throw them into a new position of equilibrium.

(IV) Allow the magnets to come to perfect rest and then turn one of them with the hand through an angle of 40° or 50°. The disturbance will be propagated along the line at a comparatively slow rate. In this way, Ewing explains "time lag."

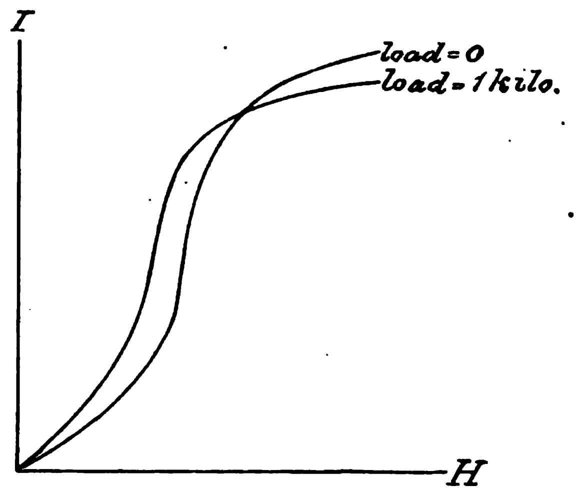


FIG. 6.—Illustrating the effect of a constant load on the *I H* curve.

The great while occupied by the magnets in coming to rest after they have once been disturbed by a change of current, continually increasing or continually decreasing, their external moment, chimes in beautifully with the work of Rayleigh mentioned in "IV" above.

(V) The effect of stress on magnetization is stated as follows in terms of the model by the author of the theory (*Phil. Mag.*, September, 1890): "When pulling stress is applied, those rows of molecular magnets which lie more or less along the direction of the stress have their stability

reduced by the lengthening of the lines of centres; similarly, rows which lie more or less normal to the stress have their stability increased. The resulting effect on the general susceptibility of the material will depend on which of these conflicting influences preponderates. Let pull be applied before magnetization begins, while the metal is still in a neutral state. The stretching of longitudinal lines and the contraction of transverse lines will not only alter the stability of those molecules which continue to lie in their original rows, but will tend to make the members of those rows which are much lengthened swing round and form transverse lines in which they will be more stable than before. We may, therefore, reasonably expect that the permeability with regard to strong fields will be reduced by pull, as it actually is both in iron and in nickel, though with regard to weak fields the permeability may be increased, as it is in iron.

"Again, the theory explains well why the effects of stress are by no means the same (1) when the stress is applied first and the magnetic force after, and (2) when the magnetic force is applied first and the stress after.

"Let a moderate magnetizing force be applied and then begin to apply stress. The first effects are in general large for the strain precipitates into instability those molecular magnets which were already on the verge of instability. This is beautifully apparent in iron (see *Phil. Trans.*, 1885, part ii, plates 63 and 64); and the theory shows why the first effects are not reversible, why they do not disappear when the stress is removed, and why it is only in subsequent applications and removals of the stress that the magnetic changes become cyclic."

(VI) The molecular motions accompanying heat will evidently free the magnetic molecules to some extent from each other and thus allow them more easily to place themselves along the axis of the magnetizing helix. The effect of heat will therefore be in the well-known direction of increasing the magnetization.

The effect of high heat in destroying magnetization is not, however, so readily understood. Ewing suggests that

it may produce rotation of the molecules and thus give the effect of zero external moment.

This much at least may be said, that nearly the whole group of magnets may be placed in rapid rotation by quickly reversing a strong current through the helix. Indeed, most any violent disturbance, such as a shock, will set a large number in rotation, which state they seem to maintain for a long while.

Some facts in the dynamical theory of heat lead one to think that this supposition of rotating molecules may not be so wild as at first it might appear.

The foregoing are some of the facts which fall into line, on the supposition of no constraint among the molecules except their own magnetic attraction and repulsion.

Prof. Ewing has given many more, and everyone should read his paper.

But there are a number of outstanding facts which do not submit so easily to explanation, *e. g.*, the difference of magnetic behavior with reference to temperature in the cases of nickel and cobalt. [*Ency.*, *Brit.*, art. "Magnetism," p. 257.]

It must not be forgotten that this model represents only one single phase of molecular arrangement. Chemical and spectroscopic phenomena indicate a vastly more complicated structure for the molecule than has yet been dreamed of. However, it is interesting to note that Prof. Ewing's hypothesis leads to conclusions which have already been derived from other lines of work.

For instance, the distinction between hard and soft iron in terms of the model is that in the former case the molecules are grouped more intimately than in the latter; while Barus and Strouhal (*Bulletin of U. S. Geol. Survey*, No. 14, p. 96), from a study of the viscous and electrical properties of hard and soft iron, have been led to think that hardness is due to heterogeneity of interior arrangement; hard temper being a condition in which the molecules are locked up into a new position of equilibrium, corresponding to a greater storage of potential energy than in the soft condition.

PROCEEDINGS.

[*Proceedings of the stated meeting, held Tuesday, September 8, 1891.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, Sept. 8, 1891.

Prof. EDWIN J. HOUSTON, President, in the chair.

Present, twenty members and visitors.

The minutes of the meeting of June 2d were read and approved.

The treasurer presented bills for printing and clerical work, which were ordered paid when approved.

Six nominations to membership were referred to the committee on admissions.

Prof. Edwin J. Houston read a paper on "The Artificial Production of Rain." There was much discussion on this subject, and also on the queries from the Question-box regarding the comparative intensity of the magnetic north and south poles of the earth, and the results obtainable in using Edelmann's electrometer as described in Ayrton's *Practical Electricity*.

The meeting then adjourned.

L. F. RONDINELLA, *Secretary*.

ARTIFICIAL RAIN-MAKING.

BY PROF. EDWIN J. HOUSTON.

[*Read before the Electrical Section of the Franklin Institute, Sept. 8, 1891.*]

Whenever a large mass of air is cooled below the temperature of its dew point, the moisture it can no longer hold as invisible vapor, becomes visible. If the reduction of temperature be but slight, the vapor appears as fog, mist or cloud; if the reduction be considerable, as rain or snow.

There has been no little attention given lately to the question as to whether or not rain can be caused to fall at pleasure on any given section of the earth—rain machines, or artificial rain producers, consisting essentially of devices whereby explosions of nitro-glycerine, or other similar substances, are obtained at fairly considerably elevations in mid-air, have been tried in different forms. As to the success of

these attempts at the artificial production of rain, the testimony appears to be uncertain or contradictory.

The idea of rain-making by mid-air explosions, is probably based on the rains that are generally believed to attend or follow great battles, Fourth of July celebrations of the Chinese character, and volcanic eruptions. Passing by the evidences produced by either the warlike or the peaceful burning of gunpowder, which at best are but vague, it may be remarked that volcanic eruptions may produce very heavy rainfalls, not only because the force of the eruption and the intense heat cause upward currents in the air, but also because of the vast quantities of vapor of water that escape from most volcanoes during their eruptions.

There is a fascination in witnessing man's struggle with the forces of nature; a struggle, be it understood, not made to oppose such forces, but rather to direct them. The former effort would be foolish, the latter must meet with success, if properly directed.

Do the scientific facts, as far as known to meteorology, give any encouragement for the continuance of the efforts of the would-be rain-makers? Let us inquire:

It is now generally agreed that the lowering of temperature necessary for the production of rain may be obtained in the following ways:

(1) By the intermingling of masses of warm and cold air.

(2) By the carrying of warm, moist air into a cold place.

In any case the cause of the rain is, briefly, the cooling of the air until it is unable to retain all the moisture it formerly held as invisible vapor, and deposits the excess in a visible form as rain.

The quantity of the rainfall will, therefore, depend both on the amount of moisture present in the air, and on the extent of reduction of temperature produced.

The first method, viz: The lowering of temperature by the intermingling of masses of warm and cold air, can never produce any very considerable rainfall, since, though the warm air is cooled by its mixture with cold air, and the tendency is, therefore, to cause the mixed air to become relatively moister, yet, at the same time the cold air is

made warmer, and therefore, relatively drier. Drizzling rains might be produced in this manner, but scarcely ever heavy rainfalls, unless both the cold and the warm air contain large quantities of moisture.

There remains, therefore, but the second way of lowering the temperature of the air, viz: by the carrying of the warm air into a colder place. This can be accomplished in three different ways:

(1) By a change of latitude, or by a warm, moist air blowing into a colder latitude. In general, the equatorial currents blowing toward the poles are the chief rain producers.

(2) By a change in altitude, effected by an ascending current, due to a heated area. Here the lowering of the temperature is due not only to the cold of elevation, but also to that produced by the expansion of the air under lower pressure.

(3) By a change in altitude, due to a mountain range opposing the progress of a wind, and thereby necessitating its gradually creeping up the sides of the mountain.

In any of these ways heavy rains may be produced and, in point of fact, they are probably the only ways in which heavy rains are generally produced.

Applying the preceding principles to the case of the modern rain machine, let us inquire as to the probabilities of its successful operation. The simultaneous, or the successive explosion of large quantities of any high explosive, in the upper regions of the atmosphere, must produce, in general, a rapid and more or less thorough mixing or stirring of the surrounding air.

The sudden expansion of the air both by the heat liberated by the explosion and by the gases evolved during the explosion, is attended by a rush outward, followed by a rush of air inwards, towards the explosion centre. The direction of this latter rush is generally radially inward. In addition to these inward motions, the heat generated may tend to produce a slight upward motion; the general effect must be, however, to produce a mixing or churning rather than an upward motion.

The immediate effect of the explosion is to produce a miniature area of low barometer, caused by the radial rush of air towards the explosion centre, and by whatever ascending current that may result from the liberation of heat.

It would be reasonable to suppose that if the explosion produces any direct effect on atmospheric conditions, the area of low barometer should follow immediately, or nearly so, after the explosion. Have such changes in the barometric pressure been noticed to follow such mid-air explosion?

So far as the mixing motion is concerned, its action to produce a fall of rain must be slight. The ascending motion might cause a rainfall, but as this motion is slight in extent, its action under ordinary conditions, must at best be but insignificant.

In either case, any decrease in temperature, and consequent increase in relative humidity, must necessarily be slightly decreased by the dry and heated gases evolved during the explosion of such substances as nitro-glycerine, dynamite or gunpowder.

It might be supposed from the above considerations that balloons containing an explosive mixture of hydrogen and oxygen would be preferable to those carrying nitro-glycerine dynamite or gunpowder, since in the former case the vapor of water results from the explosion, and in the latter dry gases. It must be remembered however, that the explosion of mixed oxygen and hydrogen produces, for the greater part, a collapse, or radial rush inwards *towards* the explosion centre, while the explosion of gunpowder or nitroglycerine produces, for the greater part, a radial rush *from* such centre.

A circumstance that appears to have been lost sight of in all the recent attempts at rain-making, is that such attempts have been apparently made regardless of the hygrometric conditions of the air. As rain is but the excess of moisture, which the warm moist air when sufficiently cooled is unable to retain, the amount of the fall will depend, as already stated, on the quantity of moisture in the air as

well as on the extent of the chilling action following the explosion or other cause. To attempt to produce rain by explosions in mid-air, irrespective of the quantity of moisture in the air, is to attempt to cause water to fall from the air when practically none is present. This is not only illogical but absurd.

It may be thought by some that the concussions caused by mid-air explosions might result in such a general movement of the surrounding air, as to cause rain to fall over an extended area. The flash of the explosion is followed by a sudden movement of the air causing the noise of the explosion. The phenomena of lightning and thunder are somewhat similar to those of artificial mid-air explosions. First we have the lightning flash, and subsequently the thunder which is a violent concussion of air. Does this concussion bring down a heavier rainfall? Popularly it is believed to do so, but the general opinion of the scientific world is that the lightning flash is the effect of a rapid condensation of the aqueous vapor, *i. e.*, of a heavier rainfall, and not the cause of such a fall. That is to say the high potency of the lightning flash is due to the enormous decrease in the surfaces of the already charged rain drops over that of the surfaces of the thousands of the separate drops that coalesce to form the single drops.

Nevertheless, the liberation of heat energy and the rapid admixture of air following the disruptive discharge may slightly increase the rainfall, or may act as a determining cause of rain over an extended area.

There is this difference between the lightning flash and the flash of an explosion, viz: The former occurs over a comparatively great length of path, *i. e.*, a space of small breadth and depth but great length.

The latter occurs in a comparatively limited space, the three dimensions of which are nearly equal.

Though lightning is not a cause of rain, there can be no doubt that if rain can be artificially produced during a period in which there is much free electricity in the air, the storm will be attended by lightning and thunder. If then, there be any increase of rain due to the presence of light-

ning, artificial rain-making will be more liable to succeed when the potential of the air, as regards the earth or neighboring clouds, is comparatively high.

The enormous expenditure of energy required to produce a rain storm over an extended area is a circumstance that would appear to give but little encouragement to man's many efforts in this direction. The amount of energy liberated by the greatest explosion man has yet effected in mid-air, is but insignificant when compared to the energy liberated by nature during even a comparatively limited fall of rain.

There is, however, an important consideration, bearing on the question of the probable success of rain-making by mid-air explosions that gives to such attempts a far greater probability of success than would appear to be warranted from the facts already enumerated. Presupposing the existence of a sufficient mass of moist air, at preferably a comparatively high difference of potential as compared with the neighboring air or the earth, a mid-air explosion might act as the determining cause of rainfall over a wide area, the balance of the energy requisite therefor, being supplied by the moist air. In a mass of very moist air there exists a store of energy which, if liberated, would suffice to cause movements of the air of vast extent. When the vapor of the air is condensed, the potential energy becomes kinetic, and, being liberated by the heat, causes ascending currents which produce a further condensation of moisture, and further liberation of energy previously locked up in the vapor.

There sometimes exist conditions in the air, in which it is, so to speak, in a state of very unstable equilibrium, and a slight determining cause may result in the liberation of the stored up energy with a resulting heavy rainfall. In such cases it would appear that there are no reasons why an explosion in mid-air should not be followed by rain. At the same time it is not unreasonable to suppose that the natural causes, which brought about such conditions, would, in many cases, continue to act and thus cause rain without artificial aid.

There are, however, meteorological conditions that probably frequently exist in certain latitudes in which heavy rains might be artificially produced by mid-air disturbances, when, without such disturbances, no rainfall would occur. Should, for example, a layer of warm, moist air exist between the earth's surface and a higher layer of cold, moist air, separated by a comparatively thin layer of air, and should such conditions exist as to maintain the two layers separate, then the breaking or piercing of the intermediate separating layer might permit such an up-rush of the warmer air through the opening, that the liberation of its stored up energy through the condensation of its moisture, would result in a general up-rush of the warm moist air and the consequent production of an extended area of low barometer. In other words, the artificial rupture of the separating layer would result in the formation of a true storm centre and a heavy rainfall of considerable dimensions. In such cases it would appear:

(1) That mid-air explosions will be more effective than explosions on the earth's surface.

(2) That directed mid-air explosions, *i. e.*, explosions in which the general effect of the liberated energy is to produce an upward rush of air, would be more effective than undirected, hap-hazard explosions.

If in such cases, considerable difference of potential exist between the layers of air, or between that of the air generally and the earth, the lightning flashes would unquestionably be effective in piercing the separating layer especially if, as would probably be the case, the general direction of the discharge be between the layers of cold and warm air.

Since, as we have seen, it is the ascending current that causes the heaviest rainfall, it would appear that mid-air explosions of such a character as to produce in general an upward rush of air would be probably more successful than undirected, hap-hazard explosions in mid-air. Such movements might advantageously be effected by the liberation of rockets with enlarged conical heads, or of any form of fire-work that would move generally upward.

Since success in artificial rain-making is probably dependent on the meteorological conditions, both of the lower and upper layers of the atmosphere, efforts should be made to enlarge our present very limited knowledge of such conditions.

Captive balloons, containing registering electrometers, tele-thermometers, tele-hygrometers, tele-anemometers, etc., might be connected by wires with recording apparatus placed on the earth's surface. The cost of maintaining such aërial stations of observation would be but insignificant when compared with the benefit that would accrue not only toward the solution of the problem as to the probable success in rain-making, but also in the aid given to the general operations of the United States Weather Bureau in particular, and to meteorology in general.

During the general prevalence of moist, warm air, when but a slight cooling is necessary to cause a general downpour, effective rain-making might be obtained by the sudden breaking or opening of cylinders of liquefied gases, where expansion would cause an intense chilling of the surrounding air; such cylinders could be readily opened by means of earth-controlled electro-magnets.

The following general conclusions may, in view of the present state of meteorological science, be properly drawn concerning the artificial production of rain.

(1) That rain can never be made to fall at will by mid-air explosions on any part of the earth's surface, irrespective of the climatic conditions there existing.

(2) That during certain meteorological conditions, mid-air explosions may result in rainfall over extended areas.

(3) That the liberation of energy necessary for such rainfalls is due not to the mid-air explosions, but to the energy stored up in the moist air from which the rain is derived.

(4) That the meteorological conditions which must exist for the successful action of mid-air explosions would probably, in most, though not in all cases, themselves result in a natural production of rain.

(5) That a comparatively high difference of electric potential between different parts of the air, or between the

air and the earth, is possibly favorable when taken in connection with other meteorological conditions for artificial rain-making.

(6) That an undirected mid-air explosion is not as likely to produce rain, as an explosion in which the main tendency of the energy liberated is to cause a general up-rush of the air.

PROCEEDINGS.

[*Proceedings of the stated meeting, held Tuesday, October 6, 1891.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 6, 1891.

Prof. EDWIN J. HOUSTON, President, in the chair.

Present, twenty-one members and visitors.

The minutes of the previous meeting were read and approved.

One nomination to membership was referred to the Committee on Admissions. The committee reported six elections since last meeting.

It was moved and carried that the President appoint a committee of three members to secure papers for the meetings.

Mr. H. W. Bartol was unable to present his paper on "The Electric Railway of Buda-Pesth," not having received the expected data with regard to it.

Prof. Edwin J. Houston described the probable production of electricity from light in the leaves of plants, and promised a more formal presentation of the subject later. In the discussion that followed, the analogous action in the selenium cell and applications of it were described.

The Question-box contained queries on the advantages and disadvantages of slow speed in motors, the practical working of the Evans frictional method of driving, the latest theory with regard to the earth's magnetism, and the practicability of dispensing with earth connection for lightning rods—all of which were discussed at some length.

The Chair appointed on the Committee to secure Papers, Dr. Wahl (Chairman), Messrs. Carl Hering and Pike.

The meeting then adjourned.

L. F. RONDINELLA, *Secretary*.

PROCEEDINGS.

[*Proceedings of the stated meeting of the Electrical Section, held Tuesday, November 3, 1891.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 3, 1891.

Prof. EDWIN J. HOUSTON, President, in the chair.

Present, thirty-five members and visitors.

The minutes of the previous meeting were read and approved.

The Treasurer's bill for printing and clerical work was approved and ordered paid.

Four nominations to membership were referred to the Committee on Admissions, who reported one election since last meeting.

Prof. Edwin J. Houston read a paper, entitled "Is Actinism a Species of Electrolysis?" Referred for publication.

Mr. Willyoung presented a communication on "Resistance Standards: their Manufacture and Adjustment." Referred for publication.

Mr. W. H. Edgerton described "Some Proposed Improvements in the Secondary Battery."

Mr. W. W. Jennings, under the title of "Jove's Autograph," exhibited and described a large and very interesting collection of lantern slides from lightning photographs, most of which were taken by himself; these showed the electrical discharge in many curious shapes, but with an entire absence in all of them of the zigzag form commonly seen in pictorial representations.

The following nominations were made for officers for the year 1892:

President—Prof. Edwin J. Houston.

Vice-President—Messrs. C. W. Pike and Carl Hering.

Secretary—Prof. L. F. Rondinella.

Treasurer and Conservator—Dr. Wm. H. Wahl.

The meeting then adjourned.

L. F. RONDINELLA, *Secretary*

Is ACTINISM A SPECIES OF ELECTROLYSIS?

By Prof. Edwin J. Houston.

[*Read at the stated meeting, held November 3, 1891.*]

In the present paper I have arranged and amplified the substance of the informal remarks made at the last meeting of the section, concerning the possible identity of actinism in the growing leaf, when exposed to the sunlight, and electrolytic decomposition.

In the growing leaf, in sunshine, a series of complex decompositions occur, which result finally in the deposition of carbon and the evolution of free oxygen.

Assimilation in plants consists, with few exceptions, in a process of deoxidation. The food materials absorbed by plants are generally highly oxidized substances, which are deoxidized during assimilation. This assimilation takes place mainly in cells containing chlorophyll, and this, almost without exception, occurs only in the presence of sunlight.

Sachs, in his *Text-Book of Botany*, says: "It is only the cells that contain chlorophyll, and these only under the influence of sunlight, that have the power of decomposing the carbon dioxide taken up by them, and, at the same time, setting free an equal volume of oxygen, in order to produce organic compounds out of the elements of carbon dioxide and water; or, in other words, to assimilate."

In nearly every species of plants the leaf is presented with one of its faces towards the sunlight, so that one face is illumined and the other non-illumined; or, at least the illumination of one face exceeds the illumination of the opposite face. This latter is especially the case with leaves that are formed of comparatively transparent substances.

That differences of potential exist in the various parts of a growing plant is a fact that is now generally recognized. Too little, however, has been done in this direction to ascertain the exact character of these differences of potential.

Probably one reason so little is correctly known to-day concerning the differences of potential of growing plants, arises from the fact that such differences of potential can be brought about by so many different causes, that probably the differences of potential arising from one cause or set of causes, mask or neutralize those produced by another cause or set of causes.

I desire in the present paper briefly to call attention to another probable source of difference of electric potential, that may still further mask or render difficult of detection the differences of potential existing naturally in growing plants.

Before doing this, however, I will briefly review some of the more important causes which produce differences of potential in growing plants. The principal of these are as follows, namely:

(1) Various chemical processes that occur in the cell walls of the growing plant.

(2) Molecular movements of liquids throughout the plant, which result in the production of diaphragm currents. These molecular movements may either be those caused during the growth of the plant, or may be caused by the mere bending of the plant, by the wind, or other cause external to the plant.

(3) Differences of potential developed in plants which would result in currents of the general character of the demarcation currents observed in animals; that is, currents due to the chemical action of the various liquid materials exuded at the surfaces of injured or abnormal plant tissue.

(4) Differences of potential due to the evaporation of moisture from the surfaces of the leaves, derived either from the rain or dew, or from the evaporation of liquid substances given off from the body of the plant.

(5) Differences of potential arising from the electrolytic decomposition of carbonic acid, or the various forms which carbonic acid derivatives assume during assimilation.

The causes above enumerated, refer to the differences of potential that have their seat in the structure of the plant

itself. Another source of differences of potential is to be found in the differences of electric potential that generally exist between the atmosphere that surrounds the plant, and the earth or soil in which it grows. These differences of potential being neutralized in the various parts of the plant itself would, of course, result in the production of electrical currents.

I desire to call special attention to the fifth head under which I have classed differences of electric potential in plants, viz: those arising from the electrolytic decomposition of the various oxygenated carbon compounds, derived mainly, if not entirely, from the carbonic acid of the atmosphere.

That the action of sunlight on growing plants should partake of the nature of electrolytic decomposition is, perhaps, to be inferred from the general views now held in accordance with Hertz's theory as to the identity between sunlight and electro-magnetic radiations or waves.

These remarks should be regarded merely as suggestions made in the line of further investigations.

As far as our knowledge of growing plants extends the oxygen which results during the general process of deoxidation, under the influence of sunlight appears to be evolved mainly from the non-illumined or darker face of the leaf, while the carbon, or the less highly oxidized carbon compounds, which are utilized by the plant for the production of its woody fibre and woody tissue, though afterwards deposited in all parts of the leaf, are probably mainly liberated at or near the illumined face.

If these facts be as above-mentioned, the decomposition in the leaf under the action of sunlight, of the carbonic acid, or its derivative compounds probably partakes of the nature of electrolytic decomposition.

In this direction I would suggest the following lines of investigation, namely:

(1) To ascertain experimentally whether there exists on the opposite faces of a growing leaf, when exposed to the full action of sunshine, a difference of electric potential resulting from the polarization which always accompanies

electrolytic decomposition; and if this be so, what is the nature of such polarization.

If such differences of potential actually exist, it would of course follow, that the illumined face of such leaves, under polarization, would be mainly electro-negative, since it is at or near this face that the carbon and less highly oxidized carbon compounds appear, while the dark or less illumined face would be electro-positive, since it is here, for the greater part, that the oxygen is liberated.

(2) Whether electrodes suitably connected to the opposite faces of a growing leaf in the presence of sunshine, will show the presence of an electric current arising from an equalization of the difference of electric potential.

The value of these differences of potential on the opposite faces of growing leaves, might, of course, be ascertained by the proper use of an electrometer.

(3) Whether a suitable leaf-battery could not be devised, by connecting, in alternate succession, the opposite faces of a series of leaves on a plant-stalk.

That is to say, connect the illumined face of one leaf with the non-illumined face of another leaf, and so on in series until any feeble differences of electric potential that there might exist are sufficiently multiplied to sensibly affect the needle of a galvanometer.

(4) A comparison of the effects of sunlight and artificial light, such as the electric light, on such electrolytic decompositions.

(5) Whether any differences exist in the case of the light produced by an alternating-current arc light and that produced by a constant-current arc light.

(6) Supposing the presence of the differences of electric potential due to the electrolytic decomposition, to be established, and the direction of the electric currents so produced, known, to ascertain whether an electric current led through the plant in the same direction as the current produced by actinism, would not tend to increase the assimilation and the subsequent growth of the plant; and, whether, on the contrary, an electric current sent in the opposite direction through the growing leaf would not tend to check such assimilation or growth.

According to some experiments recently made in France, it was shown that electric currents sent through plants under certain circumstances promoted growth. These currents were sent through the soil in which the plants were growing, by electrodes placed in the soil. The nourishing substances in a quantity of manure, placed near one of the electrodes, were clearly carried in the line of the current, or between the electrodes.

(7) To ascertain experimentally whether the converse of the proposition is true: namely, whether an electric current of approximately the same strength as that produced by actinism, when sent through the leaf in the opposite direction, would not result in the production of luminous phenomena in the leaf.

The following facts, well recognized in botany, would seem to show, to some extent at least the presence of a species of polarization in certain plants during active growth in sunshine.

In the case of those plants which bend or become concave on the side the most exposed to light: This curvature is due to the fact that a smaller growth occurs on the illumined than on the dark side. This is well recognized in botany, and such plants are called in general *heliotropic* plants. Since they are for the most part highly transparent, considerable light must therefore pass through their entire structure, and the difference in the illumination between the light and dark faces must be comparatively slight. This shows that such differences in growth may occur under comparatively small differences of illumination.

In the case of plants that turn toward the sun: It is a well-known fact that some plants turn towards the light. It is possible that this motion is in some manner the result of the polarization effected, during growth, by the sunlight.

In a series of experiments concerning the effects of the electric light on plant growth, made at the Experimental Station of Agriculture of the Cornell University, some important facts were discovered concerning electric plant-culture.

These experiments seem to show that electric light pro-

motes plant assimilation, and sometimes hastens plant growth and therefore maturity.

The Cornell experiments made during 1889 and 1890 were with the light of a constant current Brush arc lamp. Those made during 1891 were with the light of a Westinghouse alternating current arc lamp.

It would seem to be a matter of considerable interest in the case of these experiments to ascertain definitely, whether any marked differences exist between the action of the light produced by a steady current and that produced by an alternating current. In the line of investigations here suggested, it would of course seem as if the electric decomposition would be less marked in the case of the light produced by an alternating current than that produced by a steady current. And that therefore in those cases where the electric light of the steady current had proved to be injurious to the growth and assimilation of the plants, that with the alternating current light such injurious effects should be less marked.

PROCEEDINGS.

[*Stated meeting, held Tuesday, December 1, 1891.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 1, 1891.

Prof. EDWIN J. HOUSTON, President, in the chair.

Present, thirty members and visitors.

The minutes of the previous meeting were read and approved.

Three nominations to membership were referred to the Committee on Admissions. The committee reported four elections since last meeting.

The Secretary presented his annual report, which showed an increase in the membership from sixteen at the organization January 17, 1891, to sixty-four at present, with an average attendance of twenty-six at the ten meetings held during the year.

The Treasurer presented his annual report, and it was referred to the Committee of Auditors.

The following were elected officers for 1892:

President—Prof. Edwin J. Houston.

Vice-Presidents—Messrs. C. W. Pike and Carl Hering.

Secretary and Treasurer—Prof. L. F .Rondinella.

Conservator—Dr. Wm. H. Wahl.

Mr. H. W. Bartol presented a communication on the "Electric Railway of Buda-Pesth," illustrated. Referred for publication.

Mr. Carl Hering described some details of the "Lauffen-Frankfort Alternating Current Transmission," with illustrations.

Mr. Wm. S. Aldrich read a paper on "Electro-Magnetic Machinery," which was profusely illustrated, and is to be continued.

The Treasurer presented bills for printing, etc., which were approved and ordered paid.

Adjourned. L. F. RONDINELLA, *Secretary.*

JOVE'S AUTOGRAPH.

By W. N. Jennings.

[*Read at the stated meeting held November 3, 1891.*]

To watch the play of electric fire and listen to the deep echo of its voice has always been to me a most fascinating pastime. Many years ago I noted a great difference between the actual appearance of lightning itself and that depicted by artists such as Doré: in the sky, a graceful, waving ribbon of light, and on canvas, an awkward, angular, zigzag line. Thinking, perhaps, my eye-sight was defective, it occurred to me to see if the modern extremely sensitive photographic plate could catch and record the true form of an electric discharge, and thus definitely decide the question as to the zigzag or wavy line. The work was commenced, but not until September, 1882, was I enabled to induce Jove to write his autograph; a little *wavy line* about a half an inch long; thus encouraged the task was taken up with renewed interest, which has never flagged since that time, and now it gives me great pleasure to bring before the Electrical Section of the Institute, a number of photographs representing various types of lightning, the result of nine years' work: (See *frontispiece.*)

(1) A sketch of the conventional form of lightning as given by artists, and may be termed a "Doré discharge."
(2) Artificial lightning, or Holtz machine spark, the increased thickness being due to the addition of condensers.
(3) Sinuous vertical discharge, with branches, taken August 1, 1885.
(4) "Tree" form of lightning, caught June 1, 1887.
(5) Vertical discharge showing stratified lines near its lower extremity, taken May 29, 1888.
(6) Divided discharge, caught August, 1886.
(7) Double horizontal discharge (both occurring at same time), taken August, 1890.
(8) Loop form of discharge, having a spiral line running its entire length, taken June 10, 1890.
(9) Meandering discharge.

(10) Horizontal discharge, taken June 11, 1890.
(11) Vertical discharge, taken ten minutes later than 10.
(12) Parallel discharge: Two almost parallel lines converging into one main stem, taken April 17, 1891.

It will be noted that in all these photographs the wavy character is maintained, and also that the line grows thicker as the discharge progresses.*

There has been a question raised as to whether (10) really represented a lightning discharge or was merely a defect or scratch upon the surface of the photographic plate. It has been my practice to note in my diary particulars of the storm and a pen-and-ink sketch of the forms of lightning photographed as they appeared to the eye, this being done while the impression was still strongly written upon the mind. The following note appears in reference to (10), and the preconceived sketch, made before the plate was developed, has the same general outline as the photograph:

"June 11, 1890. Most remarkable storm occurred last night. At 10 o'clock took my little kodak and went off into the country. Got some beautiful low horizon effects. At midnight the storm reached us; never saw such marvellous lightning effects; all directions; one incessant blaze of glory; mostly horizontal discharges; saw several streaks turn back on themselves * * * "

The "tree form" (5) will probably explain the production of marks upon the bodies of persons struck by lightning, which have hitherto been supposed to be photographs of actual trees or branches.

Examination of the discharges upon the negatives by means of a strong lens discloses the presence of a transparent line running along its length. Whether this is due to photo-chemical action, or whether the lightning is so divided, I am unable to determine.

When lightning has once opened up a path in space, there usually follows immediately along the same line a series of discharges. If the camera be moved across its path the resulting photograph is liable to show a number of

* We are indebted for the use of a number of these pictures to the journal *Electricity*.

parallel ribbons of lightning, which has given rise to the opinion that it is not an instantaneous flash of light, but a burning streak of flame. No. 6 clearly shows statified lines near its lower extremity, although in this case the camera was rigid at the time of the discharge. I have often noticed the flight of bats during a thunder-storm, and have caught during what was apparently a single discharge of lightning a large number of instantaneous impressions of the wings of the bat in different positions clearly outlined against the sky.

In (11) a number of dark branches diverge from a light main stem. Whether this effect is the result of the reversal of the image upon the plate, or the branches represent yellow bands of light, branching from a white main stem, is an open question.

THE ELECTRIC RAILWAY AT BUDA PESTH.

BY H. W. BARTOL.

[*Abstract of paper read at the stated meeting, held December 1, 1891.*]

Ever since electricity has become not only a possibility for traction purposes, but has in fact come largely into use for that purpose, efforts have been made to arrive at some satisfactory system for use in cities whereby the overhead wire could be dispensed with.

With the above intention, extensive experiments have been made with storage batteries and some few attempts made to supply the necessary current through a conduit, having an open slot somewhat similar to that used by the cable companies, a notable instance of which was the short piece of line laid in the city of Boston a few years since.

Repeated trials have shown that up to the present time there is no storage battery which can be used to advantage, and the battery experiment having failed, many had concluded that we must adopt the trolley system or wait for further developments in electrical propulsion.

There have been several patents taken out for supplyin

the current through an underground conduit, with an arrangement whereby only a small portion of the conductor is charged at a time, the object being to prevent (what was supposed to be a very serious loss) leakage, but while experiments were being made in that direction in this country, actual practice on the other side of the ocean has shown that this is a danger more imaginary than real, and while we have been seeking to overcome this, Messrs. Siemens & Halske, of Berlin, have built and have had in operation for over two years in Buda Pesth, a road which supplies the

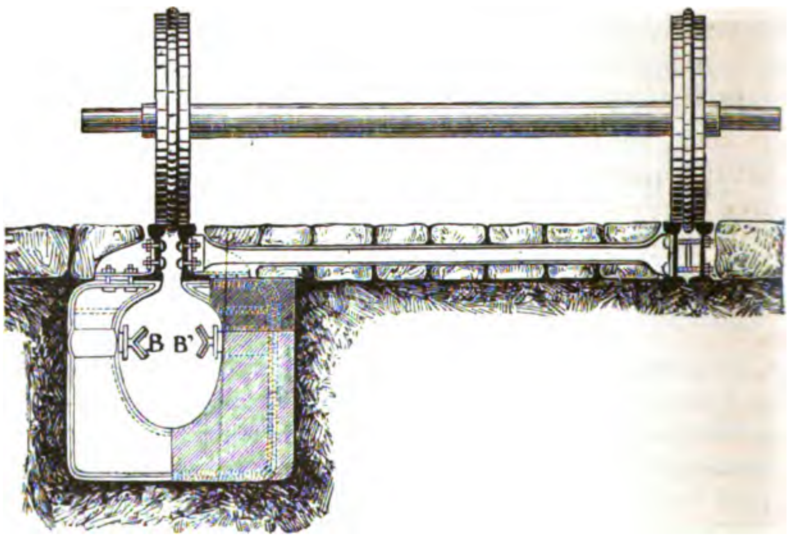


FIG. 1.

current through a conduit, and which it is now my intention to briefly describe.

By referring to *Fig. 1* you will see a conduit shown on the left, the slot being used as a groove for a flange of one of the wheels; *B* and *B'* are the conductors which supply the necessary current for driving the dynamo on the car. This conductor is made of angle iron properly insulated, and in it runs a trolley which makes contact with the two sides, viz: at *B* the current is received and at *B'* it is returned to the power station.

Fig. 2 represents a number of the iron frames in place and shows how the arrangements for switching are made.

Fig. 3 shows a truck and motor, in which it will be noticed they use a chain instead of gearing for reducing the speed and which it is claimed does away with a great deal of the noise.

The actual results obtained in Buda Pesth and the cost of building the road there are as follows: cost of road-bed, conduit, conductor, repaving, etc., $20,000 a mile. The voltage employed is 300, the ampères used in running the car after it is started, twenty-three; to start the car, however, when fully loaded, requires about eighty ampères. The weight of the car empty is about four and one-half tons, and its carrying capacity when full is forty people.

The heaviest grade in Buda Pesth is one and six-tenths per cent., but experiments on a four per cent. grade show that it requires an average of thirty-eight instead of twenty-three ampères to obtain the same speed.

We now come to some of the more practical considerations, namely: Is the road a success, and is the leakage such an item as to figure materially in the cost of operation? To the first of these questions the answer is unequivocally, Yes; to the second the answer is, that in dry weather the leakage is practically *nil*, and in wet weather on a line thirteen miles long it does not exceed three per cent., and in addition to this, is the fact that the friction of moving the car is so much less in wet weather than in dry that it actually requires less power at the power station notwithstanding the three per cent. leakage.

As the conduit is connected with the sewer at many points, no trouble is experienced from its filling with water, nor have they encountered any trouble in keeping the line free from snow, although the climate in Buda Pesth is fully as cold as that of Philadelphia.

The contact which takes the current from the conductor is a sliding one and of iron and the conduit between the iron frames is made of cement.

The speed allowed in Buda Pesth is ten miles an hour and in the suburbs eleven and one-half, which speed they

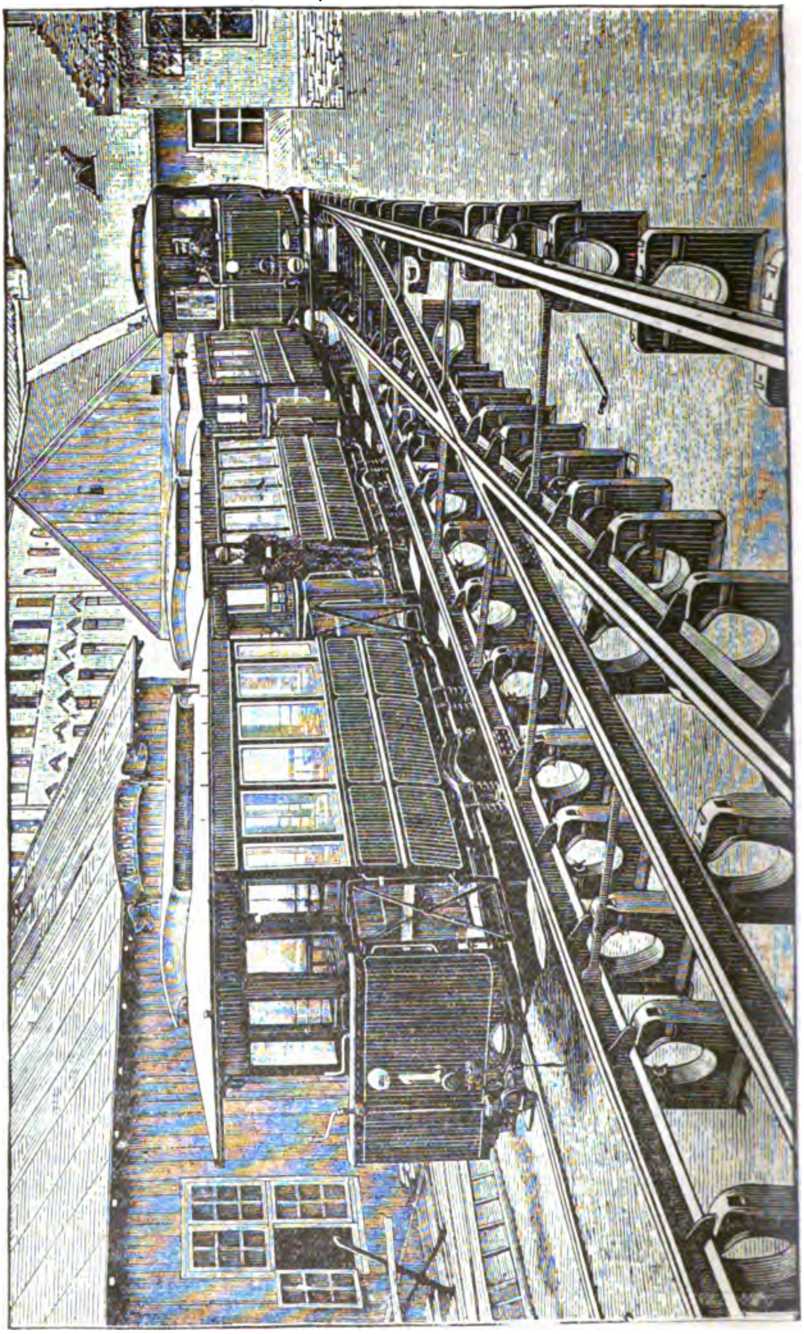


FIG. 2.

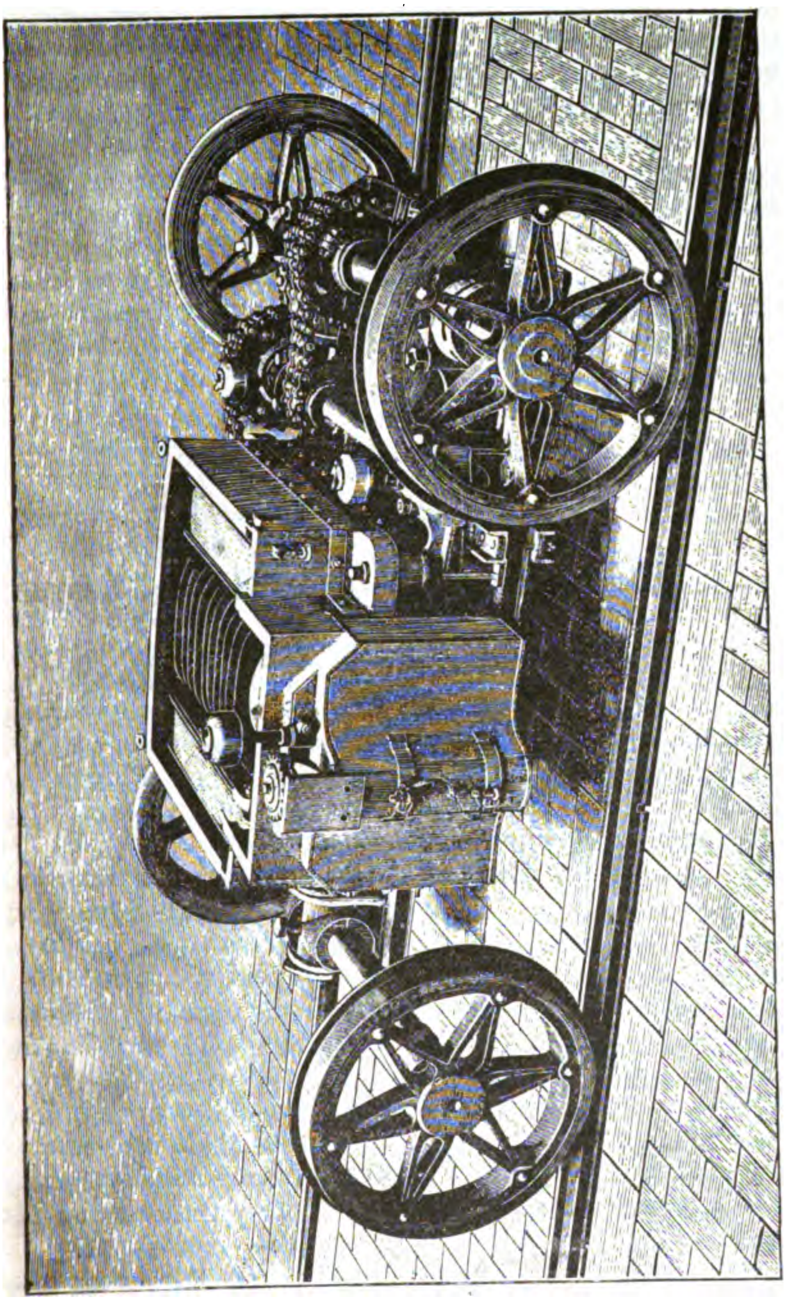


Fig. 3.

find no trouble in maintaining. The operating expenses of the company are lower than those of nearly every company using the trolley system in this country, and the company is paying dividends.

In conclusion, I might add that this system is soon to be given a practical test in this country, as a prominent railroad syndicate has undertaken to build six miles, and I am sure the public will agree with me in hoping it will be a success and a step in the direction of securing what all want, namely, a satisfactory system of rapid transit without the disadvantage of the overhead trolley or the great expense of the cable.

NOTES ON ELECTRO-MAGNETIC MACHINERY.

[FIRST PAPER.]

By Wm. S. Aldrich, M.E.,
Associate in Mechanical Engineering, Johns Hopkins University.

[Read at the meeting of the Electrical Section held December 1, 1891.]

The terms Machinery, Machines, Mechanisms are scarcely synonymous, though often so used. Early writers on the subject, among which the names of Monge, Carnot and Lanz are prominent, speak of mechanisms as means for altering or changing the direction of motion; such as the conversion of motion from continuous circular to reciprocating rectilinear motion. Ampère defined those mechanisms to be pure, which consisted entirely of rigid bodies, limiting, as it were, the definition to the means by which the motion was produced or transferred; and he defines a machine to be "an instrument by the help of which the direction and velocity of a given motion can be altered." Willis, in his *Principles of Mechanism*, follows closely, at first, with a classification based on comparative motion, subordinating the means and modes of communication by which these motions were obtained; but, later, making the mode of communication primary, and the comparative motion secondary in his classification of the elementary

combinations of pure mechanism. Rankine, in his *Machinery and Millwork*, adheres to Willis' later classification, but includes hydraulic connection as having a legitimate place among the means for the communication of motion in mechanisms. This marks a definite advance, for the means employed to communicate or transmit motion may be quite different, but the kinematic question remains the same—which is that of pure motion.

The Idea of the Kinematic Chain was brought out by Reuleaux, in his work on the *Kinematics of Machinery*, as the next step in the development of the science of machinery. He thus defines a mechanism to be "a closed kinematic chain, which is compound or simple, and consists of pairs of elements; these carry the envelopes for the motion which the parts in contact must be given, and by these envelopes all other motions are prevented." The constrainment of motion now becomes a fundamental condition for every mechanism, and subordinates the mere question of directional---relation or of velocity-ratio, as determined by the comparative motion of any two points of the mechanism. A machine is a mechanism so operated as to do work, and is stated by Reuleaux to be "a combination of resistant bodies so arranged that by their means the mechanical forces of nature can be compelled to do work, accompanied by certain definite motions."

The Electro-magnetic Connection of Moving Parts, in a mechanism or a machine, followed naturally upon the inclusion of hydraulic and pneumatic modes of communicating motion. For development in any line becomes apparent when a general identity is to be seen through many special varieties. And, however varied may be the mechanical movements of any machinery, or however simple the relative motions amidst the complicated mechanism, the ultimate analysis shows simple well-known motions, obtained by well-known pairs of elements and kinematic chains, whether such chains are composed entirely of rigid connecting elements, or of hydraulic, pneumatic, or electro-magnetic connection. Seeing, therefore, that the time was ripe for another mode of connection in mechanism, and which should

include the electro-magnetic forces of nature as among "the mechanical forces of nature [that] can be compelled to do work, accompanied by certain definite motions," Sylvanus P. Thompson has given us the term "Electro-magnetic Mechanisms," and considered them somewhat at length in connection with his work on *The Electro-magnet.* It is my purpose in these papers to speak of these mechanisms when put to do work, as electro-magnetic machines; and the general term, electro-magnetic machinery, will include such mechanisms as may be more or less useful in the conversion of motion under constrainment, and such machines as may be useful in the direct transmission of energy—by electro-magnetic means.

The Medium for the Transmission of Energy may likewise serve, as it often does, as the means for communicating motion; and, when energy is transmitted along with the conversion or transfer of motion in any mechanism, that mechanism becomes a machine. Any medium, therefore, which is of such a nature as to admit of its being made a part or link in the mechanism of the energy cycle, will serve in almost all cases, equally well for the transmission of energy or of motion; provided, that notwithstanding the deformations to which it may be subjected, the medium is capable of returning to its original condition. Some mediums or links are practically incompressible and inextensible, within the usual limits of the transmitted energy; such as, iron rods, retaining their form throughout; and a water connection, which retains its volume while altering its volume-form. Other mediums admit of practical extension, but are of little use in compression; such as, belts, wire ropes, and like flectional elements used as wrapping connectors in mechanism. Compressed air, springs, and like flectional elements admit of practical extension and compression, and are of more or less value in the transmission of energy; but, of little use as elements or links of a kinematic chain, for constrained motion. In all of these energy is transferred by and through matter in some one of its many forms—matter which follows the laws of the continuity of matter and of space, while entering as a medium in the continuity of energy.

Systems for the Transmission of Energy have therefore become quite definitely established, for long or short distances, and have taken the following broad lines of development:

(1) Mechanical transmission, by belts, wire ropes, and other wrapping connectors for long or short distances; and, by gear-wheels, links, screws, cams, ratchets, and like forms, for more immediate and direct transmission.

(2) Hydraulic transmission, with pumps, accumulators, connections, motors and presses, more or less varied in form for utilizing water-pressure.

(3) Pneumatic transmission, with the compressors and apparatus especially adapted to that medium.

(4) Electric transmission, with dynamos, line connections, regulators and motors, and chiefly used in long-distance transmission.

It is proposed to add:

(5) Electro-magnetic transmission,* in which the dynamo and motor, as generator and receiver, or as driver and follower, shall be in the same magnetic circuit; or, in which the magnetic circuit shall be used for direct and immediate distribution of energy for very short-distance transmission, in much the same way as the electric circuit is even now used for long-distance transmission.

The Ether as the Medium for the Transfer of Energy, by electric or electro-magnetic means, has been found to possess many striking analogies to other and better known mediums. By the modern theory of electricity, the electric energy is supposed to be concentrated in the ether surrounding the conductor, or other core of disturbance, and that a transfer of the ether energy takes place whenever electric energy is being transmitted from point to point. However great may be the contrast between the mechanical, hydraulic and pneumatic transmission of energy and the *etheric* transmission, it remains a fact that energy may be transmitted by all of these means, with varying degrees of

* Paper read before the Electric Club of the Johns Hopkins University, November 9, 1891, on "Notes on Electro-magnetic Transmission of Energy."

efficiency, and accompanied, if desired, by definite conversion of motion. The former three require some material connecting-link between driver and follower—some kind of contact of elements, or some pairing of surfaces—while the etheric transmission requires no such material contact or pairing; indeed, such contact may kinematically lock the whole mechanism, as an armature, in contact with its core in some special forms of this type of electro-magnetic mechanisms. The ether medium allows of the transmission of constant or varying forces, as now transmitted by more material modes of connection; and, with the peculiarities of comparative and constrained motion accompanying such energy transmission. By the displacement theory, electricity seems to act as an incompressible fluid. By the researches of Hertz, the ether appears to be possessed of some peculiar mechanical properties, such as inertia, and stress and strain manifestations. We have even come to conceive of the mechanism of the ether medium, and to picture some of the peculiar manifestations of the ether mechanism as analogous to gear-wheel mechanisms.

The Kinematic Conception of the Ether Mechanism, in combination with the peculiar mechanical properties apparently possessed by the ether medium—however far from being a true conception, may serve the passing moment till a better working hypothesis is presented. We know that the ether energy of the electric current and of the magnetic circuit, moves at right angles (normal) to the direction of the current or the axis of the magnet; also, while the instantaneous direction of motion of a point in the pitch circle of a gear-wheel is tangential to its path, the energy is transmitted radially or normal. These peculiar gear-wheel properties of the kinematics of the ether mechanism, like all good illustrations, leave us in doubt as to many points; especially, as to whether the ether gear-wheels are more or less flexibly mounted, as on springs, but with apparently limited or even fixed distances between centres. Perhaps Oliver J. Lodge may yet point out to us whether these gear-wheels, as elements in the ether kinematic chain of mechanism (speaking in the phraseology of Reuleaux) are pair-closed, force-

closed, or chain-closed. That is, whether they mesh with each other by reason of some peculiarity of their paired connection or characteristic conformation of their toothed outline; or, are by some force kept in geared connection, akin, perhaps, to the manifest tendency of the magnetic circuit to complete or perfect itself—to enclose the greatest possible number of lines of force in following the path of least resistance, and yet to remain as undeformed as possible in the presence of opposing magnetic forces—a kind of electro-magnetic force-closure; or, perhaps, these ether gear-wheels may have their centres connected by a link or chain device, not yet made clear. And the time may come when the kinematics of this hypothetical mechanism of the ether may be as definitely studied as its mechanics; and, the paths of its moving elements as clearly laid down as now in the case of link-work, cams, gearing, etc. The ether medium has already been made to yield some of its many possibilities in the applications of electricity and magnetism; and, its peculiar characteristics show it to be capable of the widest range of usefulness in the transmission of energy and of motion, for a long or short distance, and by immediate and direct, or by indirect means. And the beautiful electro-magnetic induction experiments of Elihu Thomson, the high frequency alternating-current effects obtained by Tesla, and the researches of Crookes in high vacua—give grounds for hoping that the day is near at hand when these invisible forces will be clearly seen and understood by the things that are made.

Electric Transmission of Energy is shown in simple ideal form in *Fig. 1* for long distances; in *Fig. 2* for short distances. In either case, but especially the latter, we may suppose the axes of the two armatures to be placed parallel, or in any given oblique position to each other, being then similar to transmission by belts and wire ropes. The speeds of the two shafts may be maintained constant under changes of load, or varied at will; and the rotations may be in the same or opposite directions, and, reversible at will. The current used may be direct or alternating. Power applied to drive one as a dynamo, will drive the other as a motor;

while if power be applied to both, the output will be current in the external circuit, as given by two dynamos coupled for any given output. Current supplied to drive one as a motor will serve to drive the other as a dynamo, giving an electric-motor-driven dynamo as a transformer, if

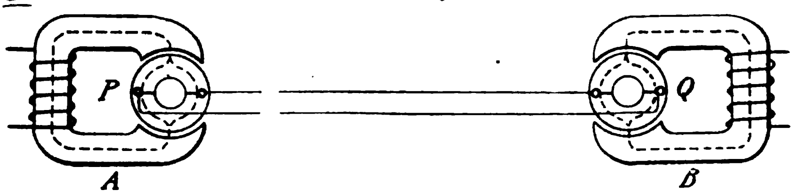


FIG. 1.—Long-distance electric transmission of energy

the two shafts are in any way coupled or geared; while, if current be supplied to both, the output is power from each machine acting as a motor. More than two machines are often used, and sometimes one dynamo operates several motors in the same electric circuit, but with individual

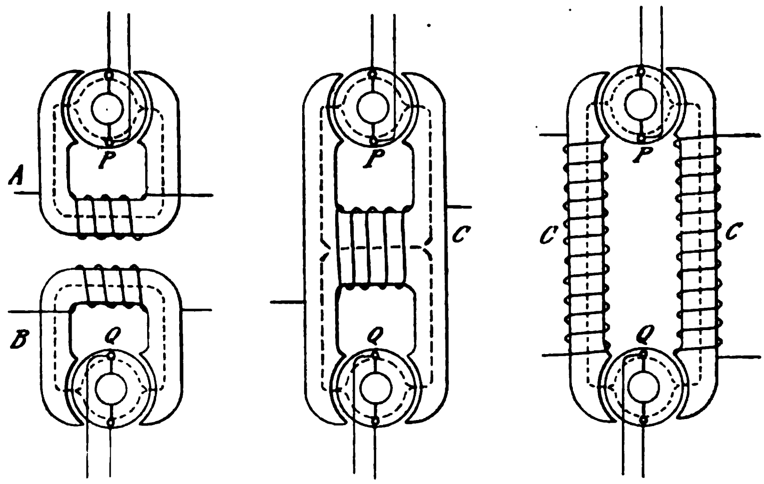


FIG. 2. FIG. 3. FIG. 4.

Short-distance electric, and electro magnetic transmission of energy.

magnetic circuits. In the figures from *1* to *12*, inclusive, *P*, *Q*, *R*, represent armatures and armatured shafts, and *A*, *B*, *C*, fields and field coils.

Electro-magnetic Transmission of Energy is understood to mean that combination for the transmission of energy in which all the armatures are in the same magnetic circuit.

(*a*) One or more of these armatures, as dynamos, may be utilized to generate current, which may be supplied to the remaining armatures, as motors, in the same magnetic circuit; or, (*b*) all the armatures may be run as motors by an external source of supply of current; or, (*c*) all the armatures may be run as dynamos by an external source of

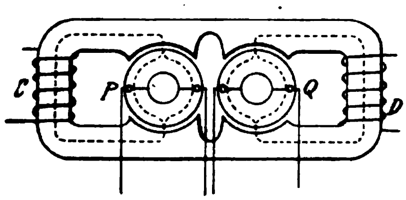


FIG. 5.

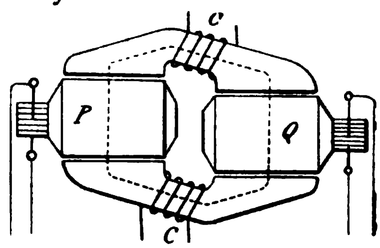


FIG. 6.

Dynamotors for parallel shafts in close proximity.

power. *Figs. 3, 4, 5, 6, 7* and *8* show such combinations of two armatures in the same magnetic circuit, or branches of the same. (*a*) If armature *P* is driven by power, as a dynamo, the current supplied to armature *Q* will drive it as a motor; or, (*b*) if current is supplied to both armatures *P* and *Q*, they will run as motors; or, (*c*) if power is applied to both armatures, current will be generated in the exter-

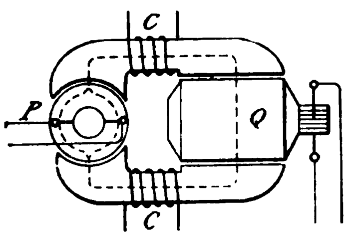


FIG. 7.

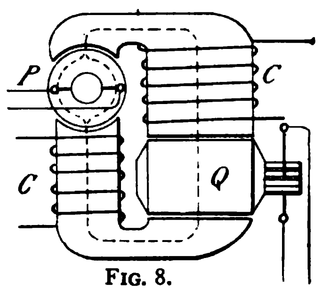


FIG. 8.

Dynamotors for intersecting and non-intersecting axes.

nal circuit. This last combination is similar to a separate-circuit self-exciting dynamo (type of *Fig. 4*), brought out by Ladd, March 14, 1867, which had two shuttle-wound armatures—a small one to excite the common field magnet, and a large one to supply currents for electric lighting. We may also arrange any one of the forms shown (*Fig. 2*, for

instance), as a dynamo-transformer, by supplying current to armature *P*, acting then as a motor, and gearing or otherwise coupling the shafts *P* and *Q*, so that armature *Q* acts as a dynamo, giving a transformed current within any given range.

Dynamotors for Electro-magnetic Transmission of Energy are combinations of armatures in the same magnetic circuit, as illustrated in *Figs. 3, 4, 5, 6, 7* and *8*, which show two armatures in the same magnetic circuit, as dynamo and motor. A dynamo-motor combination, in the same electric circuit, but with *individual* magnetic circuits, as *Fig. 2*, is really a transformer of mechanical energy; while a motor-dynamo combination, similarly arranged, is a transformer of electrical energy. The dynamotor is also a dynamo-motor combination, in the same electric and the *same* magnetic circuits, *Figs. 3, 4, 5, 6, 7* and *8*, and as such is also a transformer of mechanical energy; but it may also be used as a transformer of electrical energy. These dynamotors allow of a constant or variable velocity-ratio being electro-magnetically transmitted between two shafts arranged in any way with inclose proximity, for the immediate and direct transmission of energy. The direction of rotation as well as the velocity-ratio may be varied at will. Direct or alternating currents may be used, but preferably the latter, and very probably some form of the so-called rotary current. The dynamotor may be an independent machine, with no external circuit connections, or it may be more or less dependent upon some external source of current supply, either for regulation of velocity-ratio, or of its operations as an energy transformer.

Mechanical Equivalents of Dynamotors are those mechanical means for the transmission of energy and motion, equivalent, from the standpoint of kinematics, to the electro-magnetic means employed in the dynamotor. Thus *Figs. 3* and *4*, show dynamotors for parallel shafts, in ordinary proximity, and have their mechanical equivalents in belts, spur gearing and like means for the transfer of circular motion between parallel shafts. *Figs. 5* and *6*, show dynamotor forms for parallel shafts very close together, as

in Oldham's coupling. Shafts intersecting at an angle, such as in bevel gearing, universal joints, Hooke's joint, etc., are mechanically equivalent to the form of *Fig. 7*. Screw wheels, worm wheels, and skew-bevel wheels, are mechanically equivalent to the form of *Fig. 8*, for transmission between non-intersecting axes.

Magnetic Circuits in Parallel and in Series admit of a variety of ways of grouping two or more armatures in electromagnetic machinery. *Fig. 9* shows the simple ideal grouping in parallel or magnetic shunt, with one energizing coil. The ends of the field, at armature *R* may be closed around, and another coil put in, acting in conjunction with the coil *C*. And with or without this additional coil, separate auxiliary energizing coils, acting in the way of feeders, may be placed between armatures *P* and *Q*, and *Q* and *R*. The

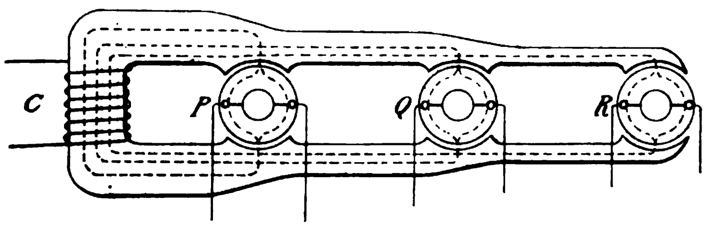


FIG. 9.—Simple ideal grouping of armatures in magnetic shunt, or parallel.

simple magnetic shunts, to which Sylvanus P. Thompson refers* may develop into useful industrial applications, such as multiple drills, operated by spindles on armatures arranged in parallel magnetic circuit. Other forms of branch magnetic circuits are shown in *Figs. 3* and *5*. The simple ideal grouping of armatures in series in the magnetic circuit is shown in *Fig. 10*, with one energizing coil. As before, auxiliary energizing coils may be placed at the other end, or between the armatures *P* and *Q*, and *R* and *S*, but these coils do not here act as feeders as they did before in the parallel arrangement, but rather as separated parts of one large coil controlling the one magnetic circuit. This

* "On a Property of Magnetic Shunts," communicated to the Physical Society, April 17, 1891. See *The Electrician* (London). Vol. xxvi. April 24, 1891, p. 764.

may be clearly seen by referring to the field coils in *Figs. 4, 6, 7* and *8*, which show the arrangement of two coils in series for one magnetic circuit.

The Electro-magnetic Kinematic Chain may be developed by reference to *Figs. 11* and *12*. Multipolar types are preferably here used. If the arm L, connecting the two fields in *Fig. 11*, be *fixed*, the combination may be used as a dynamotor. And by driving armature Q as a dynamo, by power, or by a motor secured to the arm L, armature P will operate as a motor, turning at a certain definite and predetermined speed with respect to Q. Should the armature P be slowed down by a *fixed* brake or clutching device, and the armature Q rotated as before, there will be a rotation given to the field

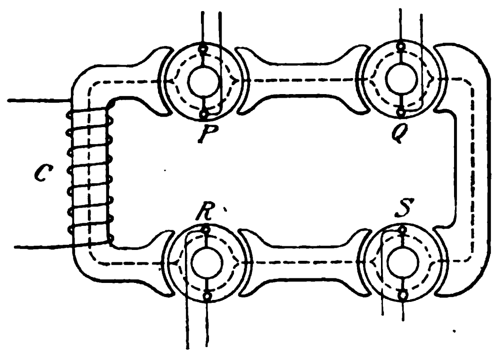


FIG. 10.—Simple ideal grouping of armatures in series, in the magnetic circuit.

C_1 of P, in the *opposite* direction to which the armature P is turning, in order that the lines of force across P may continue to be cut at the same rate as before; that is, when the field was fixed and the armature was free to revolve. If armature P be wholly stopped, its field C_1 will turn around, carrying the arm L and its appurtenances, at the same speed at which the armature was formerly turning, but in the opposite direction. If, on the other hand, the speed of the armature P be increased, by applying external power, then, to cut the lines of force at the designed rate, the field C_1 of P, and so the arm L, will have to turn around in the *same* direction as the armature P. The armature and its field form an electro-magnetic turning pair of elements; in

the first case above, acting as a motor-turning pair, and in the second case as a dynamo-turning pair of electro-magnetic elements. The placing of two armatures, *P* and *Q*, in the same magnetic circuit makes it an electro-magnetic connecting link between them; while, if placed simply in the same electric circuit, they form a combination of elements electrically linked. The electro-magnetic chain is then built up of electro-magnetic links, which connect electro-magnetic pairs of elements. Two or more armatures may therefore be electro-magnetically arranged in series or parallel, or any of the usual modifications and combinations of these groupings. And, from the kinematic standpoint, two or more armatures, with their fields, may be kinematically arranged as an electro-magnetic kinematic chain: the mechanical

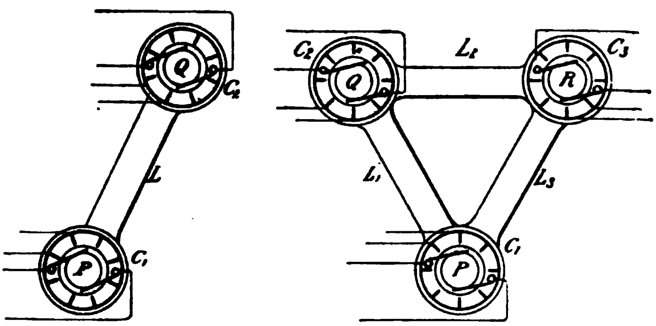


FIG. 11. FIG. 12.

Elements of an electro-magnetic kinematic chain.

equivalents of this combination may be seen in belt kinematic chains, wheel-kinematic chains, and crank (linkage) kinematic chains. In general, then, an electro-magnetic kinematic chain may be considered as a combination of electro-magnetic connecting links, so connecting pairs of electro-magnetic elements, that all parts of the chain have determinate motions; such motions being determined by the form of the elements carried by the links, and independent of the application of external force when considered merely as a change in position. *Fig. 12* shows a simple ideal electro-magnetic chain of three links. Whether the armature *P* is held fixed, or is rotated, certain definite motions may be obtained from the armatures *Q* and *R*, in either case. Fix-

ing the centres of armatures Q and R (the same as fixing the rigid connecting link between P and Q, of *Fig. 11*) would lock this three-link chain, so far as any motion of the centre of P, in space, would be concerned, and the armature P would then revolve as about a fixed centre. Kinematic chains of four or more electro-magnetic links admit of a greater variety of relative and constrained motions; and, as in any case, become convertible into a mechanism by fixing one link. The extreme flexibility of the electro-magnetic connection admits of many combinations of the simple electro-magnetic pairs for producing rotation, translation or helical motion.

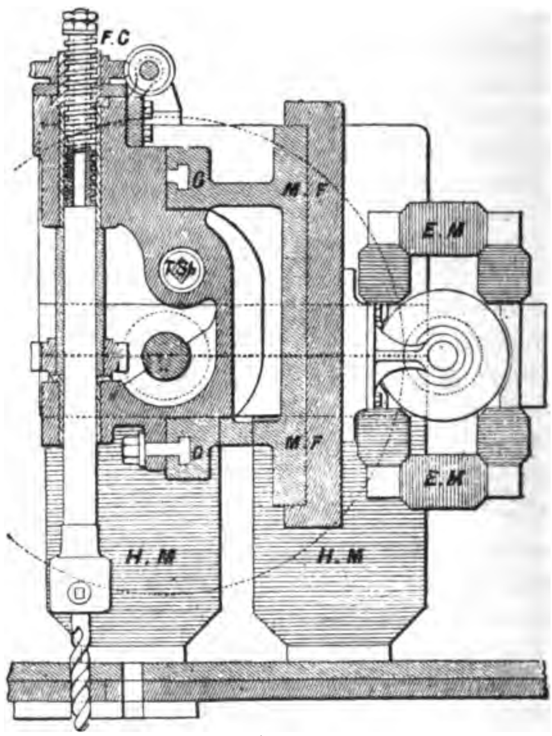


FIG. 13.—The Rowan electric drill with electro-magnetic clamp.

Some Industrial Applications of Electro-magnetic Machinery have been taken from among the many drills operated directly or indirectly by these means. Drilling operations admit of peculiarly compact and portable machines, and

ready adaptation of either rotary or reciprocating motions produced and controlled by electro-magnetic means.

The Rowan Electric Drilling Machine, with an electro-magnetic clamping device, is shown in *Fig. 13*.* The main frame, *M F*, is easily placed in position, and electro-magnetically clamped by the holding-down magnets *H M*, to the iron or steel plates to be drilled. The drill is then operated through the usual mechanism for increasing or decreasing the speed, from an electric motor, *E M*, mounted on the main frame *M F*. The feed is by hand, through the feed-gear *F G*. The drill can be moved over the work, along the guides, *G*, *G*, by the transverse shaft, *T Sh*. The Willet's portable electric drill cuts holes two and three-eighths inches diameter through two and one-half inch steel armor-plates, in position on deck, in twenty-one minutes. This work formerly required two men, working a half-day each.

The Van Depoele Reciprocating Electro-magnetic Mining Drill is a good example of the direct application of a controlled reciprocating movement. The length of stroke is about five and one-half inches, and at every stroke the drill turns automatically one-eighth of a revolution about its axis, so that the drilled hole is truly cylindrical. The forward advance is made by a feeding screw operated by hand. About two horse-power is absorbed in drilling holes from one and one-half inch to two inches diameter. In experiments at Frankfort, 1·4 inches diameter holes were drilled per minute, in gypsum blocks, to a depth of 7·9 inches with water, and 4·7 inches without water. In Odenwald granite, a hole 1·7 inches diameter and fifteen and three-fourths inches deep was drilled in ten minutes.† Two thick-wire outer coils, *1* and *3*, with a thin-wire inner coil, *2*, are wound, side by side, and secured to an iron casing, completely closing in the magnetic circuit, and so forming an efficient iron-clad construction. The drill-spindle is attached to an iron core introduced into the coils. The coils

* *Electrical World*, 1887, June 25, p. 301.

† *The Electrician*. London. Vol. xxviii, Nov. 6, 1891, p. 10.

1 and *3* are oppositely wound, so that they are equally and oppositely polarized, and connected up in series with the *rotating* brushes, R and R_2, of the generating dynamo, or of the distributing motor-dynamo; these coils are therefore traversed by an alternating current. The coil *2* is connected, at one end to the *fixed* brush F_2, and at the other end to the junction of coil *3* with the rotating brush R_1; it is therefore traversed by a pulsating current, and exerts the chief magnetizing effect upon the reciprocating iron core, with a constant polarity. Speaking kinematically of this combination of electro-magnetic elements, forming an electro-magnetic kinematic chain composed of reciprocating pairs, it is seen that the motion of the iron core is determined to a definite extent by the constant direction

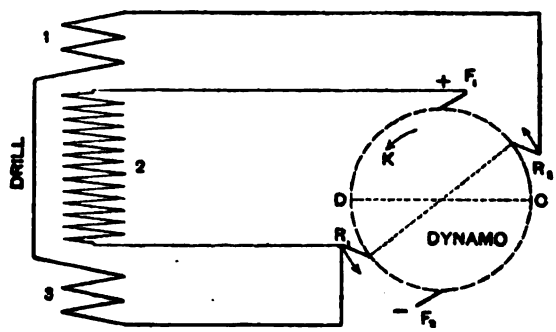


FIG. 14.—The Van Depoele reciprocating electro magnetic drill.

(polarity) and variable energizing coil *2*, in combination with the variable direction (alternating polarity) and variable energizing coils *1* and *3*. Moreover, the iron core, as an electro-magnetic link, under the influences of its electro-magnetic pairing with the energizing coils, has its motion completely constrained. This electro-magnetic constrainment of motion of the iron core link of the chain, constitutes the combination a true electro-magnetic mechanism; and when the electro-magnetic forces of nature can be compelled to do work through and by this electro-magnetic mechanism, we have a pure electro-magnetic machine. It is to be especially noted that the enveloping forms of the pairs of electro-magnetic elements, are such that there is no contact of these elements, while in mechanically-connected pairs

of elements the contact of the enveloping forms is a necessary condition to the constrainment of motion. It is therefore possible, in a pure electro-magnetic mechanism, to have constrained motion without the contact of material elements. Oftentimes practical considerations preclude the possibility of using electro-magnetically constrained motion; and, it is found best to constrain the motion mechanically by the pairing of material elements; such as, the cylindrical turning pair of elements in the dynamo or motor, and the cylindrical sliding pair of elements guiding the drill-spindle in the Van Depoele reciprocating drill.

Direct and Indirect Electro-magnetic Machines are those in which the transmission of energy, through an electro-magnetic mechanism, is of a direct or of an indirect character, according to whether the electro-magnetic forces act directly at the point of application (as in the Van Depoele mechanism), or indirectly through the intervention of other mechanism, such as a train of wheel-work, as in the Rowan machine. The indirect transmission is, in fact, through electro-magnetically *actuated* mechanisms or devices, which are of themselves essentially of another system; or which call into operation other forces of nature than the electro-magnetic forces; such as the wheel-train of the Rowan machine, transmitting the energy by purely mechanical means, from the electro-magnetic mechanism of the electric motor to the drill-spindle. It is to be remarked that the self-fixing or clamping device of the Rowan machine, acting as it does by the application of electro-magnetic traction, is an example of a locked kinematic chain, and that in this particular case such a locking, clutching or clamping action is brought about by the contact of material elements in the magnetic circuit. There are, however, examples of such a locking action with no contact of the material elements of the magnetic circuit, as may be seen in the Faraday copper-disk type of dynamo, used as a true electro-magnetic clutch or brake.

The diagram of the cycle of operations of the electro-magnetic mechanism of the Van Depoele machine, will be presented in the next paper.

REPORT OF THE ELECTRICAL SECTION.

(For the year 1891.)

The President and Members of the Franklin Institute:

The Secretary of the Electrical Section begs leave to present the following report of the proceedings of the section, for 1891:

An application for the formation of an Electrical Section, made in accordance with section 3, of article xi, of the by-laws, was presented to the Board of Managers and approved by them, and reported to the Institute with the names of the founders, at its stated meeting, December 17, 1890. After two preliminary meetings, the section was organized on February 24, 1891, by the adoption of its by-laws and the election of the following officers:

President,	PROF. EDWIN J. HOUSTON.
Vice-Presidents,	MR. CARL HERING. MR. PEDRO G. SALOM.
Secretary,	PROF. L. F. RONDINELLA.
Treasurer, *Conservator,*	DR. WM. H. WAHL.

The membership has increased from sixteen founders to sixty-eight active and associate members now on the roll, and the section has lost two members by resignation and one by death.

Seven stated meetings have been held, in accordance with the section's by-laws, on the first Tuesday of each month excepting July and August, with an average attendance of thirty members and visitors at each meeting.

The communications that have been presented during the year, may be found printed in full in the *Journal* of the Institute, and in the present volume of the Proceedings of the Section.

The treasurer's annual report shows:

Total receipts from initiation fees and dues,	$94 00
Total payments for furniture, stationery, etc.,	78 32
Leaving a cash balance January 1, 1892, of	$15 68
And bills collectible amounting to	$40 00

The growth of the section in every way during the short period of its existence has been very gratifying, and it is hoped and believed that it will continue in the future, so that its work may assist in maintaining the scientific *prestige* of the Institute in the department of electricity.

Respectfully submitted,

L. F. RONDINELLA,

Secretary.

Philadelphia, January 5, 1892.

VOL. 2. 1892.

PROCEEDINGS

OF THE

ELECTRICAL SECTION

OF THE

FRANKLIN INSTITUTE

PHILADELPHIA:
FRANKLIN INSTITUTE, 15 SOUTH SEVENTH STREET.
1893.

PROCEEDINGS

OF THE

ELECTRICAL SECTION

OF THE

FRANKLIN INSTITUTE

Vol. II.—January to December, 1892.

PHILADELPHIA:
FRANKLIN INSTITUTE, 15 SOUTH SEVENTH STREET,
1893.

PRESS OF
EDWARD STERN & CO.,
31, 33 AND 35 N. TENTH ST.,
PHILADELPHIA.

INDEX.

Vol. II, 1892.

By-Laws

of the

Electrical Section

of the

Franklin Institute.

ARTICLE I.

MEMBERSHIP.

SECTION 1. In accordance with article xi, section 4, of the by-laws of the institute, only members of the institute may be elected to membership in the section, but sections are empowered to appoint associates, corresponding members and honorary members, provided that such appointments are sanctioned by the board of members. Associates shall have the privilege of attending the meetings of the section, and of participating in its scientific discussions, but shall not be entitled to vote.

SEC. 2. A committee of admissions shall consist of seven members. They shall be appointed by the president annually. Four members shall constitute a quorum at all meetings of this committee. The adverse vote of two members shall be a rejection of a candidate. Applications for admission to the section shall be in writing, and signed by a member of the section. These shall be referred to the committee, after having been read before the section at a stated meeting. It shall be the duty of the committee, after careful consideration of the fitness of a candidate, to

vote on each name separately by ballot. This proceeding shall be secret and confidential. The committee shall send to the secretary of the section the names and addresses of the candidates elected. This committee shall have power to make its own rules of procedure.

SEC. 3. Any member-elect who shall not signify to the secretary his acceptance of membership within sixty days after notice of his election, shall be considered as having declined the same; which fact shall be duly recorded and reported to the section.

SEC. 4. If any member shall be one year in arrears for dues to the section, and shall neglect or refuse to pay the same within thirty days after notification from the treasurer, his name shall be stricken from the roll of members.

SEC. 5. All resignations shall be in writing. No resignation shall be accepted until all dues and other indebtedness shall be paid.

ARTICLE II.

MEETINGS.

SECTION 1. The stated meetings of the section shall be held on the fourth Tuesday of each month, at 8 P. M., except during the months of July and August.

SEC. 2. Special meetings may be called by the president, and shall be called at the written request of four members.

SEC. 3. A quorum for the transaction of business shall consist of seven members.

SEC. 4. At the stated meeting in November, nominations for officers shall be made, and at that in December an election shall take place for the following officers for the ensuing year:

President,
Two Vice-Presidents,
Secretary,
Treasurer,
Conservator.

The annual reports of the standing committees and officers shall be read at the December meeting.

ARTICLE III.

ORDER OF BUSINESS.

The order of business for stated meetings shall be as follows:

(1) Reading of minutes of last stated meeting and of subsequent special meetings.
(2) Reports of officers.
(3) Reports of standing committees.
(4) Reports of special committees.
(5) Nominations for membership.
(6) Unfinished business.
(7) New business.
(8) Communications and discussions.
(9) Adjournment.

ARTICLE IV.

DUES.

The annual dues of active, corresponding and associate members shall be two dollars, payable annually in advance, on the first of January of each year. Members elected after the first of October shall not be required to pay dues for that year. All members shall pay an initiation fee of one dollar.

ARTICLE V.

PROPERTY OF THE SECTION.

The conservator shall have charge of all apparatus, books, papers, models, specimens and other property of the section, except funds, and shall see that they are kept in order and readily accessible at the meetings of the section. Said property shall not be removed from the institute without the consent of the section.

ARTICLE VI.

FUNDS.

SECTION 1. No money shall be paid by the treasurer, except upon an order passed by the section and signed by the chairman of the meeting.

SEC. 2. Two auditors, appointed by the president, shall, in conjunction with the treasurer, examine his accounts and render a report at the stated meeting in December.

ARTICLE VII.

AMENDMENTS.

These by-laws may be temporarily suspended at any meeting of the section, by unanimous consent of the members present. Amendments of a more permanent character may be made at any stated meeting by a vote of two-thirds of the members present; *provided*, that such amendments shall have been presented in writing, and read before the section at a previous stated meeting.

List of Members

of the

Electrical Section.

of the

Franklin Institute, January, 1893.

A.

Achard, John W., ... Heisler Electric Co., Gloucester, N. J.
Aldrich, William S., ... Burlington, N. J.
Almon, George H., ... Hotel Washington, Philadelphia.
Arnold, Craig R., ... Chester, Pa.

B.

Bartol, H. W., ... 532, Drexel Building.
Bedell, C. H., ... 224 Carter Street.
Billberg, C., ... 3200 Arch Street.
Bosley, A. L., ...
Bullock, William A., ... 328 Arch Street.

C.

Cary, E. S., ... Queen & Co., Ardmore, Pa.
Cleverly, H. A., ... 1018 Chestnut Street.
Coleman, George T., ... North Cramer Hill, N. J.
Colvin, F. H., ... 3906 Fairmount Avenue.

D.

Davids, Richard W., ... 308 Walnut Street.
Davis, Edward W., ... Lansdowne, Delaware County, Pa.

E.

Emanuel, J. M., ... 1810 North Twelfth Street.

F.

Fearon, Charles, ... 3708 Walnut Street.
Freeman, S. E., ... Eleventh and Ridge Avenue.

G.

Genung, Nelson H., ... Queen & Co., Ardmore, Pa.
Gilpin, Richard W., ... 1332 Pine Street.
Graver, Erwin S., ... 147 East Twenty-first Street, New York.
Griggs, Dr. W. O., ... 509 Franklin Street.

H.

Hering, Carl, ... Room 31, 927 Chestnut Street.

Hering, Hermann S., ... Johns Hopkins University, Balt., Md.
Higgins, H. Allen, ... Lansdowne, Pa.
Hindley, Prof. R. C., ... Central M. T. S., 17th and Wood Streets.
Hoadley, Prof. George A., ... Swarthmore, Pa.
Hoskin, John, ... 308 Walnut Street.
Houston, Prof. Edwin J., ... 1809 Spring Garden Street.

L.

Lacy, B. F., ... Central High School.
Laird, R. H., ... 518, Girard Building.
Levis, Minford, ... 3413 Chestnut Street.
Lindsay, W. W., ... 2021 Mt. Vernon Street.
Louis, O. T., ... Queen & Co., Ardmore, Pa.

M.

Mackenzie, A. S., ... Bryn Mawr College, Pa.
Marks, Prof. W. D., ... 909 Walnut Street.
Marshall, Jas. F., ... Wm. Wood & Co., 22d & Sp. Garden Sts.
Marshall, Norman, ... 1320 Wallace Street.
McClellan, Wm., ... 144 South Sixth Street, Reading, Pa.
Mitchell, P. A., ... 1711 North Sixteenth Street.
Moore, A. F., ... 200 North Third Street.
Morris, Henry G., ... 926, Drexel Building.
Mucklé, M. R., Jr., ... 212, Drexel Building.

N.

Norris, H. H., ... 1325 Vine Street.
Northrup, Edwin F., ... Queen & Co., Ardmore, Pa.

P.

Partridge, D. A., ... 1738 Sydenham Street.
Partridge, Prof. E. A., ... Central Manual Training School.
Pemberton, Henry, Jr., ... 1947 Locust Street.
Pepper, David, Jr., ... 1827 Spruce Street.
Perot, C. Knowles, ... 308 Walnut Street.
Pfatischer, M., ... 224 Carter Street.
Pike, C. W., ... Queen & Co., Ardmore, Pa.

R.

Reese, Geo. C., ... Darby, Delaware County, Pa.
Reutlinger, Chas., ... 412 Dickinson Street.
Rittenhouse, D. S., ... 1705 North Seventeenth Street.
Rondinella, Prof. L. F. . . . . 705 Chestnut Street.

S.

Salom, Pedro G., ... 926, Drexel Building.
Scott, E. A., ... 2043 North Thirteenth Street.
Smith, T. Carpenter, ... 212, Drexel Building.

Spangler, Prof. H. W.,	University of Pennsylvania.
Spencer, Thomas,	1310 Filbert Street.
Stradling, George H.,	Northeast Manual Training School.

W.

Wahl, Dr. Wm. H.,	1436 North Thirteenth Street.
Warnick, F. C., Jr.,	1720 Susquehanna Avenue.
Whittingham, Alexander J.,	1832 Reed Street.
Wiegand, S. Lloyd,	146 South Sixth Street.
Willyoung, E. G.,	Queen & Co., Ardmore, Pa.
Winand, Paul A. N.,	210 South Thirty-sixth Street.

Y.

Young, William W.,	University of Mich., Ann Arbor, Mich.

OFFICERS FOR 1893.

President,	Mr. Elmer G. Willyoung.
Vice-Presidents,	Prof. Edwin J. Houston, Mr. C. W. Pike.
Secretary, Treasurer,	Prof. L. F. Rondinella.
Conservator,	Dr. Wm. H. Wahl.

PROCEEDINGS

OF THE

ELECTRICAL SECTION

OF THE

FRANKLIN INSTITUTE.

[*Stated meeting, held Tuesday, January 5, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 5, 1892.

Prof. EDWIN J. HOUSTON, President, in the chair.

Present, thirty-six members and visitors.

The minutes of the previous meeting were read and approved.

One nomination to membership was referred to the Committee on Admissions. The committee reported three elections since last meeting.

Mr. A. L. Church's resignation of membership was presented and accepted.

Mr. H. S. Hering gave a description of some types of recording volt- and ammeters, and suggested some new modifications.

Mr. W. S. Aldrich continued his remarks upon electro-magnetic machinery, with lantern illustrations.

Prof. Houston read a paper on "An Early Conception of Magnetic Field." Referred for publication.

The meeting then adjourned. L. F. RONDINELLA, *Secretary*.

PROCEEDINGS.

[*Stated meeting, held Tuesday, February 2, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, February 2, 1892.

Prof. Edwin J. Houston, President, in the chair.

Present, twenty members and visitors.

The minutes of the previous meeting were read and approved.

The Secretary and Treasurer reported the issue of the first volume of the Section's *Proceedings*, and the cash balance on hand in the treasury.

The Committee on Admission reported one election to membership since last meeting, and one nomination was referred to them.

Resignation of membership from Prof. Henry Crew was accepted with regret.

The Chair announced the receipt of the first number of a new and promising French electrical journal, *L'Industrie Électrique*, edited by E. Hospitalier; the unavoidable postponement of Mr. Tesla's lecture in the Institute course, and of his later appearance before the Section; and the time-limit for papers read before the Section, with its possible extension.

Mr. Carl Hering described some details of the plant for power transmission at Niagara, some features of the Frankfort Electrical Exhibition, and Burton's process of electric forging, illustrating his remarks with lantern pictures.

Mr. Wm. S. Aldrich showed the results of some experiments upon the tractive force exerted on the core of a double-coil solenoid.

Prof. Houston's paper on "Cerebro-Radiation" was deferred till next meeting.

Several queries from the Question-Box were answered, and others evoked considerable interesting discussion.

The meeting then adjourned. L. F. RONDINELLA, *Secretary.*

AN EARLY CONCEPTION OF THE MAGNETIC FIELD.

BY PROF. EDWIN J. HOUSTON.

[*Read at the stated meeting of the Electrical Section, January 5, 1892.*]

It may interest the members of the Electrical Section to know, that as early as 1668, Robert Boyle, the eminent physicist and chemist, published, concerning the magnetic field, exceedingly advanced ideas which closely resembled the modern ideas of magnetic flux and lines of magnetic force.

Boyle's publication, so far before the time of Faraday, shows the exceedingly advanced position he must have occupied at that early date, as a thinker and investigator in physical science.

Boyle was an indefatigable worker, and a voluminous writer, both in the domain of physics and chemistry, as well as in that of medicine. He taught that absolute rest had practically no existence even in bodies in apparent rest, since there existed in such bodies what is called an intestine motion of their particles. He also had original notions of what was called, in his time, effluvia, and it was in connection with these so-called effluvia that he advanced an explanation concerning the magnetic action of the loadstone, which bears a remarkably close resemblance to the modern ideas of a magnetic field and lines of magnetic force.

The quotation referred to is from the second of two essays "Concerning the Unsuccessfulness of Experiments" published in 1668. In these essays he has been pointing out the necessity for care in conducting scientific experiments, and urges, that the failure to experimentally reproduce any natural phenomenon should not necessarily call in question the accuracy of the first observer of such phenomenon, until all the sources of error that might have led to obscuring or vitiating it had been eliminated. In this connection he cites, in a quaint manner, some of the

numerous experiments that he had been led to try on the assertion of well-known scientific men, but in which he failed to obtain the results alleged to have been observed. He describes in this connection the magnetization produced by touching a steel knife-blade to the armed pole of a loadstone, as resulting in different polarities according to whether the point of the blade is drawn towards or from the equator of the loadstone.

I will quote Mr. Boyle's remarks in full in this connection:

"If on either of the Extremes or Poles of a good armed Load-stone, you leisurely enough, or divers times, draw the back of a Knife, which has not before receivd any Magnetick influence, you may observe, that if the point of the blade have in this affriction been drawn from the middle or Æquator of the Load-stone towards the Pole of it, it will attract one of the Extremes of an equilibrated Magnetick Needle; but if you take another Knife that has not yet been invigorated, and upon the self-same Extremity or Pole of the Load-stone, thrust the back of the Knife from the Pole towards the Æquator or middle of the Load-stone, you shall find, that the point of the Knife has, by this bare difference of Position in the blade whilst it past upon the Extreme of the Load-stone, acquired so different a Magnetick property, or Polarity, from that which was given to the former Knife by the same Pole of the Load-stone, that it will not attract, but rather seem to repel or drive away that end of the Magnetick Needle which was drawn by the point of the other Knife. And this improbable Experiment not only have we made trial of, by passing slender Irons upon the Extremities of armed Load-stones, the breadth of the whose Steel-caps may make the Experiment somewhat less strange, but we have likewise try'd it by affrictions of such Irons upon the Pole of a naked terella, and we have found it to succeed there likewise. How strange soever it may seem, that the same point or part of the Load-stone should imbue Iron with contrary Properties, barely as they are, during their passing over it, drawn from the Æquator of the Load-stone, or thrust towards it. But whether, and how far this Observation insinuates

the operations of Load-stone to be chiefly performed by streams of small particles, which perpetually issuing out of one of its Poles, do wheel about and re-enter at the other; We shall not now examine (though this seem one of the most likely Phænomena we have met with, to hint a probable Magnetical Hypothesis) contenting ourselves to have manifested by what plainly appears, how much influence a circumstance, which none but a Magnetick Philosopher would take notice of, may have on an Experiment."

Mr. Boyle had obtained an insight into the actions which occur during magnetization, far beyond that of his contemporaries. This fact appears to be clearly indicated by the above statement as to what he believed to be the actual operation of the lodestone; namely, that it produced magnetization by means of streams of small particles coming out of one pole and re-entering at the other pole. Change the phraseology but a trifle and leave the ideas as expressed, and we have at this early date a fair idea of the modern notion of magnetic flux.

Boyle's notion seems to have been that when other bodies were brought into this magnetic stream, they became endowed with magnetic properties by the particles or corpuscles forming the stream, passing through them, just as we now explain magnetization by the passage through a magnetizable substance of the lines of magnetic force.

In a later paper, published in 1669, on "The Absolute Rest of Bodies," he asserts that the particles even in exceedingly dense substances that are apparently at rest, are, in reality, in rapid motion. He urges that although such motions cannot be seen, yet they must exist, and cites as a proof of such assertion, the following experiment, which I will give in Mr. Boyle's language:

"I briefly answer (for I would not here repeat what I have elsewhere said on this point) by this clear Experiment, that though your Eye can discern no change in the outward and visible, much less in the more latent and internal Corpuscles of Iron: a vigorous Load-stone by passing along its Axis from one Pole of the Stone to the other, and back again, yet the Texture of the Iron is by that action of the

Load-stone so changed, that it acquires, and then loses those admirable Qualities we call the Attractive and Directive virtue or faculty peculiar to Magnetick Bodies."

And further on, in the same paper, in speaking of the well-known fact that a mass of steel when allowed to stand in an upright position for some time on the earth, is endowed with magnetic properties, he ascribes these properties to the action which the streams of corpuscles exert on it.

"To this purpose I shall only observe to you, that though a Bar of Iron having one of its ends held perpendicularly, and at a fit distance to the Lilly or Northern point of the Mariner's Compass (I mean that which points towards the North), it will, as I elsewhere mention, drive it away towards the East or West: and if this same lower end of the Bar of Iron be put into a contrary posture, it will presently lose its temporary magnetism, as I elsewhere declare. Yet if this Bar be very long kept upright in a Window or other convenient place, then, as some late Magnetickal Writers will tell you, it will have acquired a constant and durable Magnetick power. Which is a phenomenon which makes exceedingly for our present purpose, since it hence appears both that the Air together with the magnetical effluvia of the Earth that it receives in its Pores, is able without outward force to work durable changes in so solid a Body as Iron, and that the motions of the internal Parts, for these are requisite to change the Metal's Texture, are performed with a wonderful slowness, since the Bar must be very long exposed to the air, perhaps before it acquires any durable magnetism at all, but at least before it acquires so vigorous and fixt a magnetism as by this means it may attain to."

In another paper on "The Nature, Properties and Effects of Effluvia," reproduced by Shaw at a later date, in vol. i, p. 411, of the Philosophical Works of the Honourable Robert Boyle, Esq., 1725, Boyle writes as follows:

"To clear this matter, I caused some needles to be hermetically sealed up in glass pipes, which being laid on the surface of the water, whereon they wou'd lightly float, the encluded needles did not only readily answer to the load-

stone externally applied, tho' a weak one, but comply'd with it so well that I cou'd easily lead, without touching it, the whole pipe to what part of the surface of the water I pleased. I also found that by applying a better load-stone to the upper part of the seal'd pipe, with a needle in it, I cou'd make the needle leap up from the lower part, as near to the load-stone as the interposed glass wou'd give it leave. But I thought it more considerable to manifest, that the magnetical effluvia, even of such a dull body as the globe of the earth, wou'd also penetrate glass. And this I attempted after the following manner. I took a cylindrical piece of iron, about the bigness of one's little finger, and between half a foot and a foot long; having formerly found that the quantity of unexcited iron forwards its operation upon excited needles; and having hermetically seal'd it up in a glass pipe, but very little longer than it, I suppos'd that if I held it in a perpendicular posture, the magnetical effluvia of the earth, penetrating the glass, wou'd make the lower extreme of the iron answerable to the North Pole; and, therefore, having applied this to that point of the needle, in a dial or sea-compass, which looked towards the North, I presum'd it would drive it away, which accordingly it did. And having, for further trial, inverted the included iron, and held it in a perpendicular posture, just under the same point, that extreme of the iron rod, which before had driven away this point, being, by inversion, become a South Pole, attracted it; from which sudden change of the poles, merely upon the change of the situation, it also appeared that the iron owed its virtue only to the magnetism of the earth; not that of another load-stone which wou'd not have been thus easily alterable."

I need not call your attention to the marked similarity between the manner in which Boyle conceives magnetic induction to take place, and our modern notions concerning the same phenomenon. His streams of magnetic effluvia correspond exactly in direction and action to our present conceptions of magnetic flux and lines of magnetic force.

Coming now to the time of Faraday, we find in a paper, published by Faraday in the *Philosophical Transactions*,

in 1852, the following: "From my earliest experiments on the relation of electricity and magnetism, I have had to think and speak of lines of magnetic force as representations of the magnetic power, not merely in the points of quality and direction, but also in quantity." * * *

"A line of magnetic force may be defined as that line which is described by a very small magnetic needle, when when it is so moved in either direction correspondent to its length, that the needle is constantly a tangent to the line of motion." * * *

"These lines have not merely a determinate direction recognizable as above, but because they are related to a polar or antithetical power, have opposite quantities or conditions in opposite directions. These qualities, which have to be distinguished and identified, are made manifest to us, either by the position of the ends of the magnetic needle, or by the direction of the current induced in the moving wire."

As to the direction of the lines of magnetic force, Faraday, as is well known, regarded them as coming out of one pole of the magnet and passing in at the other pole, and referred to this in a paper printed in the *Proceedings of the Royal Institution*, on the 23d of January, 1852, as follows:

"The lines of force already described will, if observed by iron filings or a magnetic needle or otherwise, be found to start off from one end of a bar-magnet, and after describing curves of different magnitudes through the surrounding space, to return to and set on the other end of the magnet."

There is, of course, a danger in quoting from an early writer, of reading into the quotation a significance that it could not have had, save by the light of subsequent researches. It is far from my purpose, or desire, to belittle the researches of Faraday. I merely desire to show by a comparison of the writings of these two philosophers, the remarkable advance that Boyle had made as to the manner in which a magnet acts.

In the above quotation from Boyle it must be remembered that Boyle referred to certain effluvia which he believed were given off by the magnet. His conception, however,

of these particles coming out at one pole and reëntering the other, and his mentally endowing streams of such particles with polarity, or the possession of opposite properties in opposite directions, was certainly a remarkable advance for his times and shows how far he was beyond his contemporaries.

It is possible that other writers before the time of Boyle, or between his time and that of Faraday, may have expressed somewhat similar ideas. I merely call your attention to the quotations from Boyle as showing the remarkable grasp of magnetic phenomena possessed by this early philosopher.

NOTES ON ELECTRO-MAGNETIC MACHINERY.

[SECOND PAPER.]

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Associate in Mechanical Engineering, Johns Hopkins University.

[*Read at the meeting of the Electrical Section held January 5, 1892.*]

Electro-magnetic Reciprocating Mechanisms form a class rapidly developing in application to work requiring controlled reciprocation with definite variations of the energy of the stroke. These two questions—the kinematics and the dynamics of this mechanism—have been met in what may be styled the *multiple-coil solenoid.* It will be of interest to lead up to the form developed in the Van Depoele machine—from the electro-magnetic point of view. The several steps do not always (in some cases very rarely) coincide with the evolution of the idea from its earliest inception in the mind of the inventor. But, examining how a given electro-magnetic mechanism could have been evolved—finding how it came to be as it is—may be of service in the development of new forms—quite different in principle and application, yet worked out in more or less accord with the laws of kinematic synthesis; that is, the development of a machine for definite work and certain required motions.

Multiple-coil Solenoid Mechanisms require to be energized by currents of variable potential, producing variable and shifting magnetic fields of force, which may be caused to act in conjunction with or in opposition to each other. These potential variations in the respective coils may be produced and controlled by adjustable external resistances, or by one or more rotating brushes around the commutator of a dynamo.* In either case, variable undulating (pulsating), or alternating currents, may be produced from a source of constant potential. The loss of energy in adjustable resistance being very objectionable, the rotating-brush mechanism is used—fulfilling the fundamental purpose. This is to convert the electrical energy of a continuous-current machine, rotating at its most efficient speed, into undulating currents having any desired rapidity of succession, corresponding to the number of reciprocations of the plunger core working as a piston within the solenoid. The kinematic question is therefore met by fulfilling the conditions of comparative motion in mechanism—(Willis) the directional relation between the rotating brush and the reciprocating plunger, and their velocity ratio of movement. And it satisfies another condition, stated by Reuleaux, in that the relative motion between the two elements is under constrainment even if this is brought about by electro-magnetic stresses in the ether medium, rather than by the molecular stresses of rigid connecting links of a kinematic chain. The mechanics of this mechanism—the statics and dynamics of its own peculiar medium for the transmission of energy, show that the electro-magnetic forces of Nature can be compelled to do work. And the ether medium, with its induced electro-magnetic streses, being as much a *resistant* body as more material mediums with their molecular resistance to change of form or of volume, constitute this combination an electro-magnetic machine, from an adaptation of the definition of Reuleaux, given in the former paper. The tubes of force of the magnetic field may change their *form* to a

* As in the Van Depoele Pulsating Electric Generator, United States Patent, No. 422,855, March 4, 1890.

very great degree, but they remain unaltered in *volume* ; and, it is the resistance of the tubes of force to any change of volume, which answers as well for the performance of work or the transmission of energy or motion, as the resistance of a bar of rigid material to any alteration of its length or general form.* Also, examined in the light of Sylvanus P. Thompson's treatment of electro-magnetic mechanisms, † the one under consideration possesses the characteristic feature that it is a combination in which power is transmitted electrically along a wire, and made to produce, through its electro-magnetic combinations, certain mechanical motions.

The Single-coil Pulsating-current Solenoid is shown in *Fig. 1*, diagrammatically, in combination with the rotating brush *M*

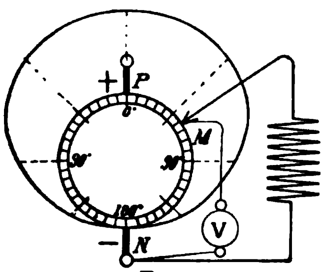

FIG. 1.

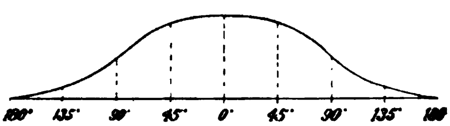

FIG. 2.

Single-coil pulsating-current solenoid mechanism, with ideal integrated curve of potentials.

and one terminal of the stationary brushes *N*, of the dynamo. What Sylvanus P. Thompson has called the integrated curve of potentials, being the total or integrated potential taken at each bar all round the commutator (by the indicated voltmeter connection) has been plotted in its simple *ideal* form, around the commutator in *Fig. 1*, and as referred to rectangular coördinates in *Fig. 2*.

It is the line-integral of the ideal (sine) curve of induction ; and, any ordinate represents the total induction from

* Compare Rankine, *Machinery and Millwork*, chap. iv, sec. viii, art. 207. Thurston, Introduction to *Kinematics of Machinery*, Van Nostrand's Science Series, No. 54, p. xi. Kennedy, *Mechanics of Machinery*, chap. i, sec. 1.

† *The Electrical World*, 1891, January 17th ; also, in his work on *The Electro-magnet*.

the fixed brush N up to that point of the rotating brush M. With the rotation of the brush M, there is produced a variation of potential through the solenoid coil, a corresponding undulation of current strength and so a variation of ampère turns and a rise and fall of the intensity of magnetization of the solenoid core. This causes the plunger to be drawn into its coil with variable energy, according to the laws of the magnetic circuit, by which it continually so tends to place itself that it shall be in the field of maximum induction at any one time. The action is only in one direction—after reaching the maximum, at 180°, the plunger gradually falls out of the coil by its own weight, or is retracted by a spring to its original position. If the rotating brush is held at any position around the commutator, the plunger

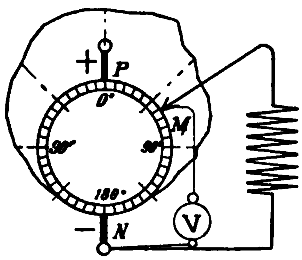

FIG. 3.

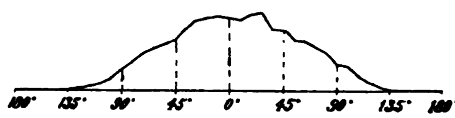

FIG. 4.

The single-coil electro-magnetic mechanism, with real integrated curve of potentials.

will remain in its corresponding position for that point; being in more or less stable equilibrium between the electro-magnetic stresses of the ether medium, and the force of gravity or of a retracting spring. It would be possible to give a slight oscillation to the plunger in this position, as it is under the action of the contractile energy of the tubes of force, which is a property that the current has conferred on the ether medium surrounding the coils; by this its tubes of force develop a marked tendency to shorten in the direction of their length, and spread out in directions at right angles to their length. The integrated curve of potentials represents an entirely ideal condition of the cycle of operations; and does not indicate that the intensity of magnetization will proportionally vary in more than a quite

general way. The several resistances in the path of the magnetic circuit—that of the air gap and of the iron portion—as well as the counter-electromotive force dependent on the speed of reciprocation, and the movement of the plunger into and out of the field of force, will continually vary the resultant effect of the variable field of force. It becomes then, rather difficult to plot exactly the real flow of magnetic stress along the corresponding positions of the plunger. It belongs to the class of intermittent mechanisms; and, like single-stroke devices, requires reactive forces to restore it to its original position. From the point of view of electro-magnetic kinematics, it is a simple one-circuit (magnetic) mechanism, of constant direction (polarity) and variable intensity (of magnetization or of induction).

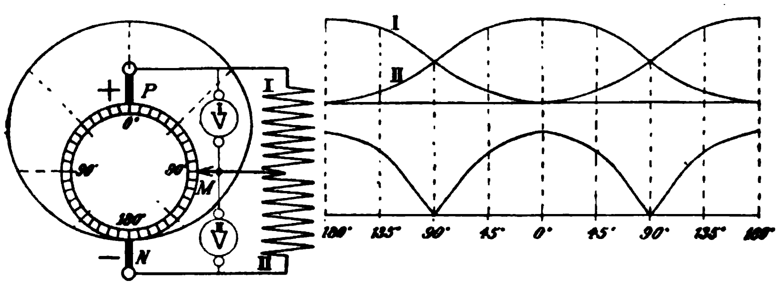

FIG. 5. FIG. 6.

Two-coil pulsating-current solenoid mechanism.

Figs. 3 and *4* show the *real* curves of the distribution of potential, taken with voltmeter, as indicated, and with no other external circuit, from a small separately-excited motor, run as a dynamo, with constant field.

The Two-coil Pulsating-current Solenoid has its outer terminals connected to the fixed brushes, *P* and *N*, as in *Fig. 5*, and the inner join of the same coils to the rotating brush *M*. The resultant action of the two fields of force of the coils, may be quite different: (*a*) according to whether the two coils are connected up to operate in conjunction with each other, as two parts of one coil, called a differential coil-and-plunger mechanism, by Sylvanus P. Thompson; or (*b*), when the two coils are connected up in opposition to each other, producing variable

electro-magnetic stresses working against each other. In the former case the mutual actions of the two solenoid coils are reciprocal, the energizing effect of one of the coils increasing from zero to a maximum, while the other decreases from a maximum to zero, as the rotating brush is moved around the commutator a half turn, indicated in a general way by the ideal curves of integrated potential, the upper curves of *Fig. 6.* This ideal cycle of operations being completed shows two nodal points—positions of electro-magnetic equilibrium—when the plunger is under the action of balanced electro-magnetic stresses. This equilibrium is more or less stable, depending upon whether the two coils work with or against each other. The lower curves, *Fig. 6*, represent what may be termed the effective electro-motive force, being found by taking the differences of corresponding ordinates of the upper curves. The portions between the nodal points are really of opposite sign, representing a reversal of the resultant effect of the variable magnetic fields. The plunger, on passing the nodal point, as a position of zero pull, goes more completely into the range of action of the increasing magnetic field and out of the decreasing field of the other coil. The combination of the two coils acting in conjunction, results in an almost constant magnetization of the plunger, so that it has generally a steady pull and a regular movement, in which it follows the movement of the field of maximum induction of the solenoid coils, determined by the rotating brush *M*. It is a double-acting mechanism, giving two controlled reciprocations of the plunger for one rotation of the brush *M*. For producing hammer blows, regulating switches may be used to vary the intensity of the magnetic field, according to the location and character of the work. The electro-magnetic conversion of continuous circular into reciprocating rectilinear motion may be accomplished with equal facility and regularity, for almost any intervening distance, an advantage not possessed by its somewhat analogous mechanical (kinematical) equivalents of finite connecting rod, nor of the so-called infinite connecting rod.

Multiple coil Pulsating-current Solenoids admit of varying

the power stroke, as in hammer-blows, to meet requirements of the work, while there is a very light return stroke to prevent excessive wear and tear of the machine. By winding the solenoid coils in three or more sections, of equal resistances, longitudinally disposed, and connecting the two or more forward sections in parallel with the supply wires and the back section singly—the current through this section will be correspondingly less than that through the other section with joint resistance in parallel.* This arrangement will therefore throw the preponderance of power in the forward stroke.

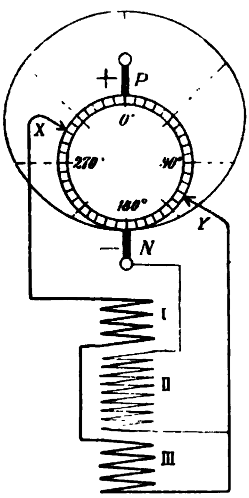

FIG. 7.

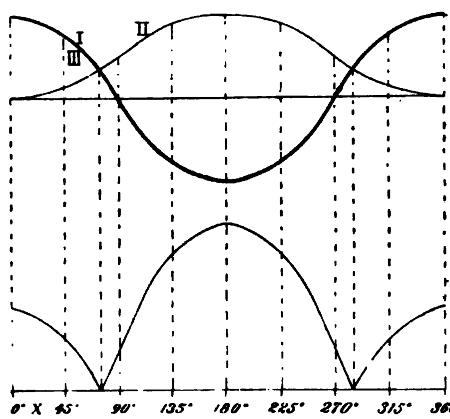

FIG. 8.

Three-coil pulsating- and alternating-current solenoid.

The Three-coil Pulsating- and alternating-current Solenoid, with two rotating brushes, is shown in *Fig. 7*. Another but similar diagram,† was explained at the close of the former paper. At the same time that there is a controlled reciprocation, the combination of the pulsating current through the fine-wire coil *II*, with the alternating current through the coarse-wire coils *I* and *III* gives a heavy

* Van Depoele's method, set forth in United States Patent, No. 422,855, March 4, 1890.

† From *The Electrician* (London). Vol. xxviii, Nov. 6, 1891, p. 10.

power stroke in the forward direction and a light return stroke. *Fig. 8* shows this in the form of the potential cycle, the light-line curve *II* being the ideal curve of the integrated potential for the pulsating current of coil *II*, and the heavy-line curve *I—III*, that for the alternating-current coils *I—III*. The lower curve represents, as in *Fig. 6*, the differences of the corresponding ordinates of the upper curve. There are several pecularities of these curves; and, though entirely ideal, may serve to aid us in forming some notion of the real distribution of electrical energy in the solenoid coils. The nodal points are both on the return-stroke end of the plunger-cylinder, encasing the mechanism. The long ordinate at the centre shows a very heavy power-stroke forward, while the short ordinates at the ends show light return strokes, with more or less of a cushioning effect. The action of the energizing polarizing coil *II*, shows how its pulsating current—in the one case causes a very rapid increase of the resulting maximum induction, and in the other, at the end of the stroke, having no effect, as it simply rises and falls between zero and a maximum. The alternating current passes from maximum to maximum in opposite directions, and cuts the pulsating curve nearer the weak end of each case. The iron core, under the chief energizing coil *II* is not electro-magnetically equivalent to a permanent magnet core, for it is now *variably* energized in one direction, at about the proper points. But, in the latter case, its constant magnetic field would seriously interfere with this very arrangement of the two kinds of currents to produce maximum forward stroke. By reversing the connections of coil *II*, the other stroke will be a maximum. More than three coils may be used, and the respective positions of the pulsating and of the alternating-current coils may be reversed, or otherwise arranged to suit the requirements of the work.

Derived Mechanisms from Multiple-coil Solenoids admit of many industrial applications. For instance, it gives at once a kind of electro-magnetic *dash-pot*, buffer, cushion, brake or clutch for reciprocating movements. And this possesses capabilities of adjustment not usually found in rigid or

even flectional-element mechanisms, of changing quickly and surely the intensity of the tractive force as well as the position of its static equilibrium. Periodically varying the speed of rotation of the brush *M* will result in corresponding variations in the rate of reciprocation, with or without changing length of stroke. The length of stroke may be changed by auxiliary and solenoid coils. On the other hand, the speed relations may be maintained constant, and the power stroke varied at will, or both may be varied to any desirable extent. Another modification, which would produce multiple nodal points, would give multiple-reciprocation mechanism (*reduplication*, of Willis), obtaining four, eight, or more reciprocations for one rotation. For the stress nodal points indicate the electro-magnetic dead centres, of which there must be as many as the number of reciprocations desired. So with electro-magnetic *cams*—the stroke of the plunger may be made to follow any given law of cam curves or spirals, as the Archimedian or logarithmic, by simply controlling the rotating brush *M*, according to the same law. And the stop, dead and change points of ordinary cam plates may be controlled with equal facility by this electro-magnetic combination. Electro-magnetic *ratchet* mechanisms, where there is no special return or reversal of motion, may be equally developed from the solenoid mechanism, chiefly of the multiple-coil types, with the coils connected up in series, as in the port-electric and other electro-magnetic package-carrying devices.

The Cycle of Operations of Electro-magnetic Machinery possesses features characteristic of the ether medium employed. The fundamental cycle is necessarily that of the physical condition of the medium at each point; following this are the energy cycles of the medium and throughout the mechanism, and the kinematic cycle of the mechanism of transmission. Or, perhaps more generally, the transformation or conversion cycles of the medium would be considered first, then the transmission cycles of the intermediate mechanism and machinery, through which the transformation cycles indicate the performance of useful work by the so-called mechanical forces of nature. Each of these ele-

ments of the complete cycle—the ether medium and the mechanism of transmission—may again be considered, especially with reference to the *mechanics* of the elements involved; that is, the mechanics of the electro-magnetic stresses of the ether medium as of a *resistant* body,* and the mechanics of the molecular stresses of the material elements of the electro-magnetic machinery. In considering in a somewhat analogous way, the mechanics of the medium and the mechanism of the steam engine, Prof. R. H. Thurston† has extended the point of view along the lines of Rankine, and thus groups under the heading of *Mechanics:*

(1) *Statics*, treating of the relations of forces in any system or medium, when no motion results from their action.

(2) *Kinematics*, treating of the relations of motion simply.

(3) *Dynamics*, or kinetics, treating of the action of forces accompanied by motion.

(4) *Energetics*, treating of the transfer, transformation, transmission or modification of energy, under the action of forces, from one mode of manifestation to another, and from one body to another.

Examining, for a moment, the application of the above to electro-magnetism, with ether as the medium, it will be found that the lines have already been mathematically laid out by Maxwell in the direction of electro-statics, electro-kinematics and electro-dynamics, resting somewhat anteriorly upon Faraday's researches and posteriorly upon Hertz's experiments. We have noted the statical action of the electro-magnetic stresses, when under more or less stability of equilibrium, as in the solenoid mechanisms; the kinematic conception of the ether mechanism, as stated in the former paper, has served fairly as a working hypothesis, in lieu of a better; while the dynamical conception has shown the ether to be a suitable medium for the transfer or transmission of energy accompanied by definite motions. In order to investigate the complete cycle of operations of

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* *Resistant* in the sense of acting as a body constantly maintaining its volume while undergoing any kind of alteration of its volume-form.

† *Manual of the Steam-engine*, Part I, pp. 298 and 304.

an electro-magnetic mechanism, the whole of its mechanics should be developed—for the ether medium and for the machine elements. This, therefore, involves the *energetics* of the medium, giving the etheric energy cycle (electro-dynamic), as we have for the steam engine the thermo-dynamic cycle. And, the energetics of the ether medium may come to be studied by autographic records of its energy cycle, bearing the same relation to the electro-magnetic mechanism that the indicator card does to the distribution of energy in the steam-engine mechanism.

Differential Electro-magnetic Mechanisms may consist: (1) of variable-speed or power (or both) combinations effecting their purpose by electro-magnetic action, not necessarily of itself differential; (2) of variable-action mechanisms having a differential effect brought about in the electro-magnetic stresses themselves. In the former case, the mechanism is inherently differential, whether controlled, operated or actuated electro-magnetically or pneumatically for instance; such would be a differential screw, pulley or other *mechanically* differential mechanism. In the second case, we have the two-coil solenoid; the solenoidal electro-magnetic balance, and the dynamotor balance shown later, the differential action being due to a preponderance of a simple or of a resultant magnetic field over a surrounding field or fields.

Epicyclic Gear-wheel Mechanisms are differential in character, as may be seen by referring to *Fig. 9*. The motor armature M_1 and gear-wheel A are secured to a sleeve, loosely turning on shaft PP, and the motor armature M_2 and wheel B, similarly placed on shaft $S\ S$. Three principal combinations of these three elements of a simple kinematic chain are possible. (1) If the arms $X\ X$, connecting the shafts, are fixed—one machine will drive the other as a dynamo—the fields being supposed secured to the arms $X\ X$. (2) if shaft $P\ P$ is held in fixed bearings, field of M_1 stationary, and both motors set in operation, the arms $X\ X$ will carry combination around the shaft $P\ P$, when the motors revolve at different speeds. The arms $X\ X$ will turn around in a direction dependent upon the direction of rotation of the

motors, and at a speed proportional to the speed of the motors and the number of teeth on the wheels. When the wheels have the same number of teeth: (*a*) and the motors revolve at the same speed in the opposite direction, there will be no rotation of the arms; (*b*) motors revolve at different speeds, the arms will turn at a speed of half the difference of the motor speeds, and in the direction of the greater one. (3) If shaft $S\ S$ is fixed, instead of $P\ P$, field of M_2 stationary, similar combinations will produce similar results in effecting the rotation of the arms. Several minor combinations are possible in each case, but the above serve to show

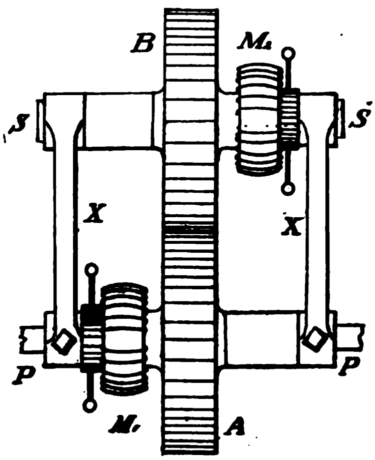


FIG. 9.

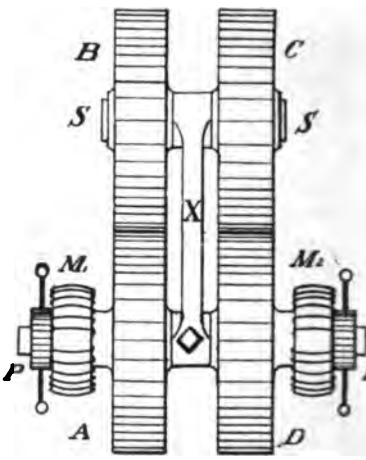


FIG. 10.

Epicyclic spur-wheel mechanisms, driven by electric motors.

the differential nature of this form of a simple epicyclic gear-wheel train.

In *Fig. 10* motion is communicated to the wheel B through the wheel C on same sleeve as B, and geared to D on same sleeve as motor armature M_2, loosely mounted now, on shaft $P\ P$. This is permanently mounted in bearings, and has no rotation, when the gear wheels $A\ D$ and $B\ C$ are of same size, and the motors M_1 and M_2 revolve at same speed in same direction. When the motors M_1 and M_2 revolve in the same direction at different speeds, the arm X (keyed to shaft $P\ P$) rotates at a speed equal to half the difference of the motor speeds.

In *Fig. 11* bevel wheels have been substituted for the spur wheels of *Fig. 10*, reducing the number; as the bevel wheel *B*, loosely sleeved on the arm *X* meshes with *A* and *D*, and so performs the mechanical functions of both the wheels *B* and *C*, of *Fig. 10*. The motors M_1 and M_2 are mounted as before, and cause no rotation to the arm *X* or shaft *P P* when they revolve in opposite directions at the same speed. When so revolving, at different speeds, they rotate the arm *X* at a speed of half their difference of speeds, in the direction of the greater. This is the fundamental form of the Edison epicyclic street-car gear. A slight alteration in the speed of the motors above or below their normal speed, or one above and the other below the normal, will rotate the car-axle *P P*, and drive the car forward or backward, according

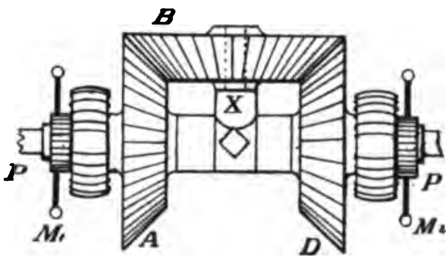


FIG. 11.—Epicyclic bevel-wheel train of mechanism.

to the direction of rotation of the motor having the greater speed. Sometimes the arm *X* and wheels *B C*, *Fig. 10*, are duplicated on the other side of the shaft, as in *Fig. 16*, which distributes the strains, but in no way changes the kinematical relations. A similar addition to *Fig. 11* is to extend the arm *X* and loosely mount fourth bevel wheel on it, between *A* and *D*. All of these are simply electrically-driven epicyclic gears.

Epicyclic Electro-magnetic Mechanisms may now be derived by substituting dynamotors (or double motors if needed) for the pair or pairs of gear-wheels. In *Fig. 12*, the dynamotor combination *C D* has been substituted for the two wheels *C D*, of *Fig. 10*, discarding motor M_2. For armature *D* being mounted on the same sleeve with *A* and M_1 and so driven by M_1 now operates as a dynamo, supplying current

to armature *C*. This is on same sleeve as wheel *B*. The dynamotor fields are secured to arm *X*. Therefore, while the motor *M* is run at a constant speed all the time, the dynamotor *C D* being then operated as a variable-speed dynamotor, the speed of *C* may be varied at will. As the fixed speed-relation between the gear-wheels *A* and *B* cannot change—an increase or decrease of the speed of *C* from the normal, will cause the arms *X X* to rotate the shaft *P P*, in the same way that *Figs. 9* and *10* would operate if the motor M_1 were run at constant speed while motor M_2 should

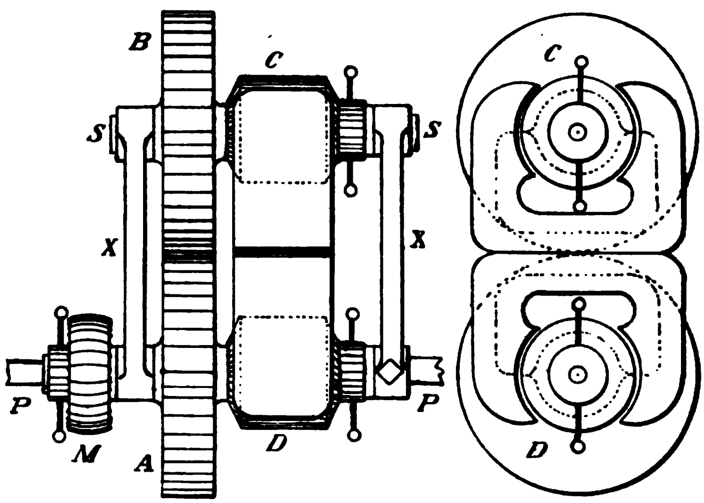


FIG. 12. FIG. 13.

Combination of spur-wheels and dynamotor in an epicyclic train.

be varied as we have now supposed motor *C* to have been. *Fig. 12* might also have been derived from *Fig. 9* by putting in the dynamotor *C D* instead of the motor M_2. *Fig. 13* is a side view of the dynamotor of *Fig. 12*. This is yet a combination of mechanical and electro-magnetic elements. Drop the wheels *A* and *B*, giving form in *Fig. 14*.

Fig. 14 is the true electro-magnetic and epicyclic mechanism combined. The dynamotor fields are secured to the arms *X X*. The motor *M* driving it, tends to drive the armature *A* as a dynamo, but both *A* and *B* are connected up with the external circuit, either as a constant or a

variable-speed dynamotor. Therefore, if motor *M* runs free (open circuit) there is no rotation to the arms *XX*, while *A* and *B* are revolving all the time at a nominally fixed speed-relation.

(*a*) Now, upon operating *M*, as a motor, but against the rotation of *A* (and therefore, as a brake to *A*), the armature *A* will be slowed down, which will cause the field of the dynamotor and arms *X X* to rotate in the opposite direction of armature *A*, in order to continue cutting the lines of force across armature *A* at same rate as before, and so to maintain the constancy of the nominal speed-relation between armatures *A* and *B*. Should the armature *A* be

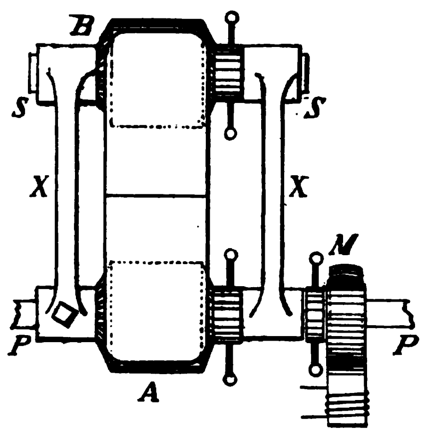


FIG. 14.—Epicyclic electro-magnetic mechanism.

slowed down till it stops, the dynamotor field will increase its speed of rotation till up to the former speed of its armature *A*, and will maintain that speed, still in the opposite direction, as long as armature *A* is held stationary, by the armature of *M*, on its sleeve, being now electro-magnetically clutched by its stationary field. Slowly releasing armature *A*, will cause it to react against its dynamotor field, tending to stop it; when armature *A* is once more free the arms *X X* are stationary again.

(*b*) By again operating *M* as a motor, but causing its armature to rotate in the same direction that it had been going when free, and increasing its energy gradually, it

will cause the armature *A* so to react upon its dynamotor field, as to continue to cut across the lines of force at same rate as before, which will therefore give a rotation of the dynamotor in the *same* direction as its armature *D*.

Besides controlling the motion of the dynamotor field (and so of its arms *X X*, and shaft *P P*), entirely by motor *M*, it may be partly controlled by regulating the external circuit supply to the dynamotor fields and armatures.

Fig. 15 is a double form of this mechanism, derivable from *Fig. 14*, by adding another dynamotor, or from *Fig. 12*, by substituting a dynamotor *A B*, for the gear-wheels *A B*. One or both of the dynamotors may be variable-speed

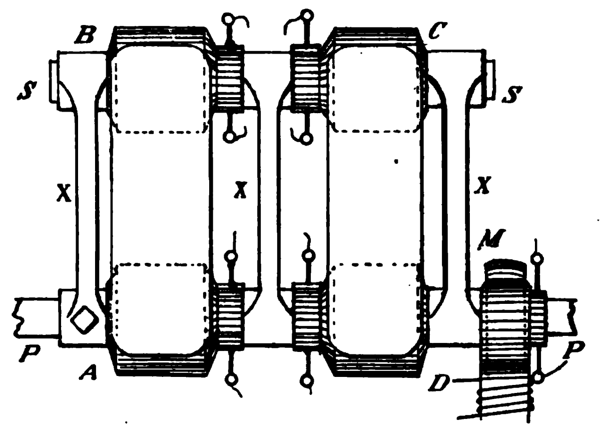


FIG. 15.—Double form of epicyclic electro-magnetic mechanism.

combinations; and one only or both may therefore be under control of the external circuit. The armatures *A*, *D* and *M* are all on same sleeve, loosely mounted on shaft *P P*. The armatures *C* and *D* are on same sleeve, loosely mounted on shaft *S S*. The operation is analogous to that of *Fig. 14*.

Fig. 16 is a double form of the gear wheel form of *Fig. 10*, and *Fig. 17* is a double form of the combination shown in *Fig. 12*.

Three-armature Dynamotors are shown in *Figs. 18* and *19*, the former having a two-branch magnetic circuit, and the latter a four-branch circuit. Either of these will serve for the combination shown in *Fig. 17*. All of the armatures of

either *Figs. 18* or *19* may be run: (*a*) as dynamos with electrical output of current; (*b*) as motors, with mechanical output of power; or, (*c*) one or more may be run as dynamos supplying current for the remaining armatures, as motors, in the same magnetic fields. The differential operation of the branch circuits *C* and *D* would result in no flux of lines across armature *Q*, when the fields of *C* and *D* were exactly

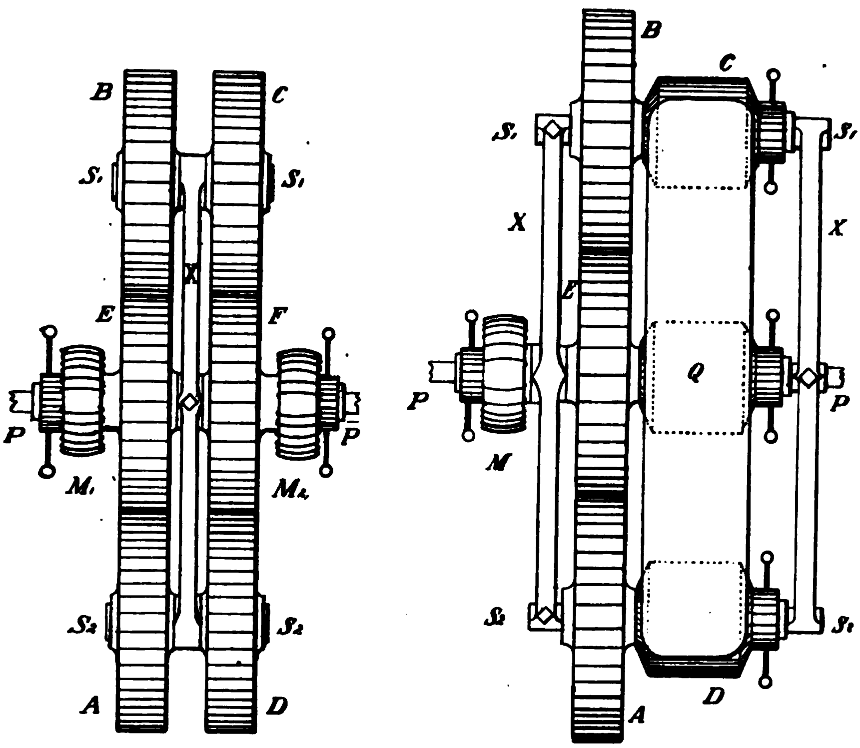
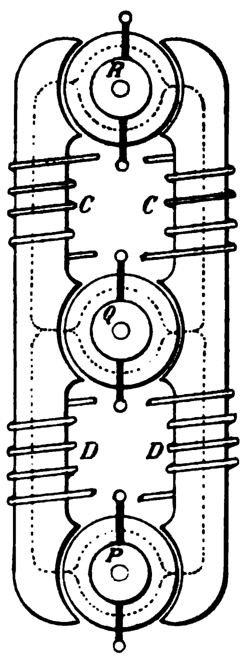


FIG. 16. FIG. 17.

Double forms of epicyclic mechanisms, derived respectively from *Figs. 10* and *12*.

balanced. We have then electro-magnetic equilibrium, as formerly in the solenoid mechanism, and more or less stable, according to the character of the balanced fields of force. Moreover, there is constant air-gap resistance here, independent of the position of the balanced circuits, as was not the case with the differential coil-and-plunger mechanism. This eliminates the many disadvantages of the electro-magnetic

balance in the solenoidal form, and may give this type, or a modification, some useful purpose to fulfil as a measuring instrument. When there is an exact balancing of the magnetic flux from C to D, on each side, there will, of course, be no rotation of the armature Q. And when there is not a balance, it will either cause a rotation of the armature Q (if the dynamotor field is fixed), or cause an angular swing of the field (if the armature Q is held stationary). This swing of



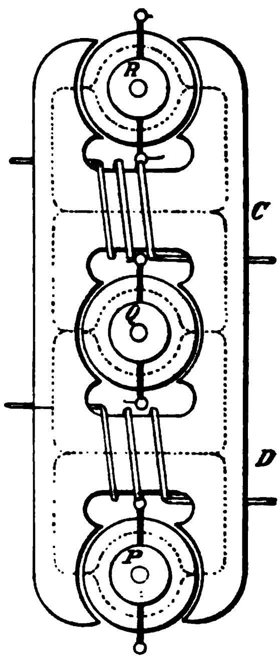


FIG. 18. FIG. 19.

Three-armature dynamotors.

the field is somewhat analogous to the swing of the field of a dynamo when mounted in the form of the Brackett cradle dynamometer. Within certain limits the angular deflection is a measure of the torque.* Brackett states that if the counterbalancing effort of the spring balance or weights be removed, the field will perform a complete revolution and

* Used at the Stevens Institute of Technology, 1884, and described in the *Electrical World*, Jan. 5, 1884.

go on revolving, increasing its speed till it and the armature (practically) revolve together; when, of course, there is no work done but in overcoming internal and external friction. This action of the field and armature is analogous to that considered for the combinations of epicyclic mechanisms, *Figs. 14* and *15*.

The Efficiency of Dynamotor Transmission should approximate to that of the motor-dynamo transformers, the one being practically the reverse operation of the other. Sylvanus P. Thompson has considered* continuous-current transformers to be capable of a high average efficiency. Lahmeyer employed the principle of the dynamotor,† consisting of an armature turning nominally without load, as a variable resistance, to regulate the (constant) number of turns of the working armature. In Lahmeyer's constant-current transformer,‡ of the one-armature type, wound both for high tension supply and low tension demand, all in one magnetic field—we have a form of construction of high practical value. There is higher efficiency at less cost and decreased size, with less sparking than in motor-dynamo transformers. With equal excitation this transformer works with a higher degree of magnetic saturation—because the reactions of the armature coils balance each other, a condition obviating sparking. The efficiency of transformation is about ninety-two per cent. The Bernstein constant-current transformer § has its motor armature wound with thick wire, the dynamo armature with thin wire, entirely separated longitudinally, and turning in a common magnetic field, which is excited by the current in the primary wire. Being a series-field, with primary field in series with the thick-wire coils of the magnet—the speed varies directly as the electro-motive force required, a peculiarity of some importance in certain work. Elihu Thomson's continuous-

* Paper before the International Electrical Congress, on "Constant Current Transformers," Paris, 1889. See *Electrical World*, Sept. 21, 1889.

† *Electrical World*, Oct. 12, 1889.

‡ *Engineering*, London, May 29, 1891, p. 642.

§ *Electrical World*, Jan. 25, 1890.

current transformer,* for a three-wire system, has an armature consisting of a double winding of two separate sets of coils, the counterparts of each other in potential energy, and each set having a brush and commutator of its own. The armature windings of this so-called "compensator" are of quite low resistance and designed to give, at its normal speed, an electro-motive force respectively equal to that existing between the side wires and centre wire of the three-wire system. Isolated plant forms of dynamotor transformers are to be seen in the telephone and hotel service electrical work.† And several typical forms of dynamotors have been exhibited at the Frankfort Exhibition last year, details of which may be seen by referring to the current journal reports and correspondence of that period. Respecting the peculiar conditions likely to arise in using the dynamotor in form of an epicyclic mechanism, the field and armature both revolving, Patten has developed a form‡ of dynamo with *revolving* fields and armature. With careful design, construction and management of operations, the dynamotor should range as high as ninety per cent. efficiency as a maximum.

The Kinematics of Electro-magnetic Machinery has been touched upon in the foregoing sections, chiefly with reference to the propriety of including electro-magnetically connected mechanisms with previous typical forms, the mechanical equivalents of dynamotors, and the conception of the electro-magnetic kinematic chain. It remains to be seen whether this portion of the subject may be further developed along existing lines of treatment and classification, as outlined by Willis, Rankine and Reuleaux; or, whether it may not be found to require a peculiarly distinct treatment, owing to the special need of considering the character of the medium, and its own kinematics and dynamics. But, in the present state of our knowledge it is well to guard against too rigidly

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* *Electrical World*, April 16, 1887.

† *Electrical Engineer*, New York, Dec. 23, 1891.

‡ *Electrical World*, Nov. 26, 188[illegible].

adhering to only the kinematical and mechanical conceptions of the ether medium. It is not that the true conception is necessarily otherwise; but, because the electro-magnetic mechanism appears to have many well-known mechanical equivalents. For, almost all the kinematical problems may be solved by electro-magnetic connection, in some cases more readily than by mechanical devices.

The Characteristic Features of the Ether Medium led Maxwell to identify the two phenomena of light and electro-magnetic waves, basing upon this identity his electro-magnetic theory of light. Prof. Henry A. Rowland remarks* that "as yet we cannot conceive of the details of the mechanism which is concerned in the propagation of an electric current. . . According to our modern theories of physics there must be some medium engaged in the transmission. . . . That medium which is supposed to extend unaltered throughout the whole of space, whose existence is certain, but whose properties we have yet but vaguely conceived; . . . we have finally completely identified the ether which transmits light with the medium which transmits electrical and magnetic disturbances." And, regarding the possibilities bound up in the intensity of the electro-magnetic stresses which are capable of being induced in the ether medium, Mr. A. E. Kennelly states† that they are far in excess of any stress which we can exert without the cohesion of matter. He estimates that one cubic inch of electro-magnetically stressed air, magnetized to a flux density of 5,019 lines per cubic centimetre, and alternated 227 times per second, would store and release energy at an average rate of one horse-power. So that for range of adaptability in meeting the requirements of comparative and constrained motion, as well as for great concentration of energy in the transmission and transformation of energy—the ether medium stands out alone, yet with a rapidly increasing field of application.

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* "On Modern Views with Respect to Electric Currents." *Transactions American Institute of Electrical Engineers.* Vol. vi. No. 7, July, 1889.

† *Transactions American Institute of Electrical Engineers.* Vol. viii. No. 11, Nov., 1891.

PROCEEDINGS.

[*Stated meeting, held Tuesday, March 1, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 1, 1892.

Prof. Edwin J. Houston, President, in the chair.

Present, thirty members and visitors.

The minutes of the previous meeting were read and approved.

The Treasurer reported the cash balance in the treasury, and presented bills for printing and clerical work, which were approved and ordered paid.

The Committee on Admissions reported one election to membership since last meeting.

Mr. C. W. Pike read a paper on "The Constant Shunt Method for the Measurement of Continuous Currents," with blackboard illustration. Referred for publication. In discussion thereon, Mr. Carl Hering stated that this method had been used successfully at the Munich Exhibition of 1882, and by himself at the Institute's Electrical Exhibition of 1884. In the latter case copper wire was used throughout, making the rate of temperature variation more regular. Mr. Willyoung also stated that he had used this method satisfactorily.

Prof. E. J. Houston read a paper on "Cerebral Radiation" which was discussed at some length and referred for publication.

Mr. Carl Hering gave some data submitted by the Oerlikon Works for the power-transmission plant at Niagara. The current furnished would be equally suitable for motors, arc and incandescent lights. The dynamo is a three-phase, separately-excited machine of 5,000 horse-power, and ninety-six per cent. efficiency. Its drum armature is made up of copper bars, is ten feet in diameter, and, running at 250 revolutions per minute, will furnish a current in each of the three coils of 2,000 ampères, at 600 to 700 volts. The current from each machine feeds through two 2,500 horse-power transformers, capable of reducing from 25,000 volts. Cost of the line to be $20,000 for 32,000 metres, to carry up to 10,000 horse-power. Total estimated cost, including generators, exciters, transformers and lines, to be $180,000.

A query from the Question-Box regarding the temperature coëfficient of a Weston voltmeter was discussed at some length, and satisfactorily answered.

The meeting then adjourned. L. F. RONDINELLA. *Secretary.*

RESISTANCE STANDARDS: THEIR MANUFACTURE AND ADJUSTMENT.

By Elmer G. Willyoung.

[*Read at the stated meeting, held November 3, 1891.*]

I shall speak to you for a very brief time this evening on the subject of electrical standards of resistance. The standard of resistance is, to my mind, by far the most valuable standard with which we have to do in actual work. Considering only the quantities involved directly in Ohm's law, which are about the only quantities of any particular value or meaning to four electricians out of five, the standard of resistance is almost the *only material* standard which we can possess. The unit of current is a standard but it is a standard which only exists by definition and is not an actual tangible and physical thing, while the standard of E.M.F. which shall give an exact unit or multiple of a unit is yet to be discovered; a standard cell, to be sure, giving a definite E.M.F. at a definite temperature and whose rate of variation with temperature is accurately known, is now a comparatively easy thing to secure, but the care necessary in its use together with the decimal value of its E.M.F. are both considerably against its being rated as high, practically, as the standard of resistance. It must also be borne in mind that, having a standard of resistance, we may obtain the value of any E.M.F. by the solving of $E = CR$ where C is known from the amount of electrolytic deposition taking place in a given time out of a suitable solution; the amount of copper, silver, or other metal deposited out of such a solution in a given time by a given current being always a definite and exact one to be found in any text-book upon the subject.

The standard of resistance, as generally known, is a length of wire of one kind or another, wound upon a spool, mounted in a convenient case to protect it from injury and moisture, and having its resistance at some given tempera-

ture definitely determined; a true standard also has its rate of variation of resistance for change of temperature accurately known. Sometimes one coil is mounted up alone and sometimes many coils of different values are put up in the same mounting.

In the manufacture of standards of resistance a great many qualities are required of the resistance wire which shall be used. It should have high specific resistance, in order that the standard may not have too much bulk; it should have as small a temperature coëfficient of resistance as possible, in order that its value may be easily obtained at any reasonable temperature without the making of troublesome calculations; it must not change its resistance in time; it must not be oxidizable by the air or by the medium in which it may be enclosed, since this would change the constitution and hence the resistance of the wire; and it must be of a hardness suitable for handling in manufacture and adjustment without injury. The requirement of high specific resistance immediately compels us to reject copper, iron, aluminum, silver, and all other pure metals except lead, antimony and bismuth. The softness, difficulty of working, and high temperature coëfficient as well as many other reasons would throw these last three out of the account. The matter of temperature coëfficient alone, in fact, would compel us to reject all pure metals since they all increase roughly about twenty-five per cent. in resistance between 0° and 100° C., except iron, which increases about forty per cent. We are, therefore, led to try alloys. Dr. Matthiessen, chairman of the sub-committee (of the Committee on Electrical Standards of the British Association), from 1862–65, having in charge the investigation of the properties of wires with reference to the selection of a suitable one to be used in the standard of resistance, decided upon by the British Association and now known as the B. A. Ohm, examined very exhaustively a large number of wires, among which were pure iron, silver, copper, thallium and other metals, and a great many alloys; he finally concluded that silver alloyed with 33·4 per cent. of platinum was the best alloy obtainable. This alloy, known as plati-

num silver, is still used by English makers; it has a specific resistance of twenty-four microhms and a per cent. variation per degree C. of $\frac{31}{100}$. In selecting this alloy we see that the requirements of high specific resistance and low temperature coëfficient have both been observed, the resistance of platinum silver being about sixteen times that of copper and its temperature coëfficient less than $\frac{1}{10}$ that of copper.

With reference to the constancy of resistance in wires it may be well to mention that many metals and alloys seem to alter in electrical resistance with time, or on being subjected to change of temperature. In an investigation carried on by J. Bergmann, a German electrician, in the latter part of 1889, he reports that, after raising to and maintaining at 300° C. for one hour and then cooling, the resistance of several substances changed as follows:

	Per Cent.
Copper decreased,	2·4
Aluminum "	5·0
Magnesium "	6·8
Zinc "	2·4
German-silver increased,	$\frac{2}{10}$

Mr. Tomlinson, a little earlier, found a somewhat similar result in the case of iron wire, which decreased in resistance about one-quarter per cent. after several heatings to 100° C., and subsequent cooling. Dr. Matthiessen, in the investigations previously alluded to, found a considerable time change in a number of the alloys and wires, which he experimented upon. It may be of interest to state here that three of the original platinum-silver coils determined by the British Association through Dr. Matthiessen and his colleagues at the time of the adoption of the B. A. Ohm were found last year, when carefully examined, to have developed an increase of resistance of about six parts in 10,000, or about $\frac{6}{100}$ per cent., quite an appreciable amount as standards go. The committee having these last comparisons in charge suggested that this change in resistance was only temporary, and due to strains in the wire produced by lowering it to 0° C., at which temperature the measurements were made; they have, however, not yet been able to verify this idea. A time change is, however, to be noted in a large

number of metals and alloys where strains are not taking place. This time change in resistance, as Dr. Matthiessen suggested, is probably very largely due to a gradual annealing effect, as it is particularly noticeable in hard-drawn wires. It has also been observed to be in a marked degree a property of wires containing zinc and to be lacking, except to a very small extent, in wires free from zinc; here it is possible that zinc may gradually crystallize out, since it does easily crystallize, and the homogeneity of the wire thus being altered, the change in resistance may be accounted for.

It is almost self-evident that the resistance of a metal or alloy is a function of its density; hence, all causes tending to change the density of the resistance metal will also tend to change its resistance. It is quite reasonable to expect, therefore, that an increase of resistance should be observed after a wire is wound upon a spool. A wire wound up on a spool not over eight times its own diameter will increase from one-half to two per cent. in resistance; a part of this increased resistance is due to the increased hardness caused on the inside of each turn, by the bending stress, and hence gradually falls away as the wire slowly anneals. For this reason, it is unsafe to send out a resistance standard as correct until several months have elapsed after winding.

Several years ago a wire was brought out in England known as "platinoid." It was said to be an alloy composed of ordinary German-silver with one or two per cent. of metallic tungsten added. It has a specific resistance of about thirty-two microhms and a temperature coëfficient of $\frac{22}{100}$ per cent. per degree Centigrade. I have analyzed this several times but have never been able to detect any tungsten; two or three friends have done the same with the same result. Whether or not any tungsten is used as the wire is now made, is, therefore, not certain. During the week since reading this paper, I have been informed by an electrician that the tungsten "burns out" in the process of manufacture. The properties of this alloy are, however, about as reported. It is nearly as cheap as German-silver, and during the time over which my own

observations have extended shows no time change; at least if any change has taken place in the coils in our possession, is has been by less than $\frac{1}{100}$ per cent. The wire is hard, practically non-oxidizable and easily handled. It is now being used in all the standards sent out by Queen & Co., and proves satisfactory in every way. I have here in my hand a wire recently sent me by the Aluminum Brass and Bronze Company, of Bridgeport, Conn., and claimed by the manufacturers to have thirty-five times the resistance of copper together with an extremely small temperature coëfficient, less than $\frac{1}{10}$ that of German-silver. I have not had an opportunity to test the accuracy of these statements as yet, having been too busy with other work, but hope soon to be able to do so. According to the *Electrical Engineer*, of October 21, 1891, there is also claimed for this wire a tensile strength of 70,000 to 100,000 pounds per square inch, with eighty twists in six inches, and with a lower resistance, a tensile strength up to 140,000 pounds per square inch You see it is of a pale-rose color and looks as if it might contain considerable copper. I suspect it is a variety of manganese-copper made up of about seventy per cent. of copper and thirty per cent. of manganese, with perhaps a small percentage of nickel. Mr. Edward Weston experimented on some of these alloys a couple of years ago and found one of them to have a negative temperature coëfficient; his statement to that effect was received with considerable incredulity at the time, but has since been thoroughly verified. According to Drs. Feusner and St. Lindeck, in *Zeitschrift für Instrumenten Kunde*, February, 1891, an alloy composed of seventy per cent. copper and thirty per cent. manganese had a resistance of about five times that of German-silver and a temperature coëfficient of but $\frac{4}{1000}$ per cent. per degree Centigrade, while an alloy of seventy-three per cent. copper, three per cent. nickel, and twenty-four per cent. manganese had a specific resistance a little less than three times that of German-silver, and a *negative* temperature coëfficient of $\frac{8}{1000}$ per cent. We see, hence, that it ought to be entirely possible to obtain a wire having a zero coëfficient, *i. e.*, not changing resistance at all for change of

temperature by properly combining the constituent metals of this alloy. The obtaining of such an invariable standard is a "consummation devoutly to be wished" in electrical work as accurate work is very troublesome and tedious where long decimal coëfficients have to be applied, and this becomes particularly the case where several sets of coils are used in the same investigation having different temperature coëfficients. Dr. E. S. Nichols, of Cornell University, and others have made successful attempts to obtain resistances having a zero coëfficient working along another line; they have taken a rod of carbon and soldered to its extremities a length of wire of some metal or alloy; since carbon decreases and wires increase their resistance with rising temperature, it is evident that by using a suitable wire and proper proportions a combination might be found which when placed in a circuit in parallel would remain of the same resistance at any temperature. The difficulty of soldering to carbon as also the care necessary in adjusting prevent, however, such resistances from becoming commercial possibilities; the carbon is also too sensitive to changes of pressure and to strains.

A strictly standard resistance is, according to the practice of the best makers, adjusted to anything within from $\frac{1}{10}$ to $\frac{1}{100}$ per cent. of absolute accuracy. A *single* coil would not be considered a "standard coil" unless it were accurate within from $\frac{1}{50}$ to $\frac{1}{100}$ per cent. absolute accuracy. To obtain this high accuracy of adjustment it is easily seen that very exact methods of measurement must be employed: should we attempt to measure an inch within this limit of error, the error could not be over $\frac{1}{10000}$ inch, an exceedingly small quantity. Various methods have been suggested and employed by different parties at different times. An apparatus designed by Prof. Fleeming Jenkin, and used somewhat by the British Association Committee in 1862, consisted of essentially, an ordinary Wheatstone's Bridge with the connection between two adjacent arms, consisting of a short, straight length of resistance wire. If, now, one galvanometer contact be on this straight wire and the other at the junction of the two opposite arms of the bridge, and *S*, one

of these opposite arms, be the coil to be adjusted to R, the other of the opposite arms, and the arms adjacent to the straight wire be designated C and A we will have

$$\frac{C}{A} = \frac{R}{S}$$

we now interchange R and S and have

$$\frac{C}{A} = \frac{S}{R}$$

this will demand a new position of the galvanometer contact upon the straight wire and the distance moved over on the straight wire is a measure of the difference in resistance between R and S.

Suppose that C and A each have 100 inches of the same wire as the straight wire and that we have had to move over one inch in reversing R and S, then R and S agree within one per cent. Now we adjust S closer to R and substitute for C and A two new coils C' and A' each of 1,000 inches wire. If now we again adjust so as to move over one inch in reversing we are within $\frac{1}{10}$ per cent. of accuracy; and so by continually adjusting S to R we may obtain gradually closer approximations to accuracy if we, at the same time, substitute other coils for C and A. But this process is, at the best, but a cut-and-try one and exceedingly tedious. A complete description of this method and convenient apparatus will be found on p. 38, of *Reports of Electrical Standards*, published by Spon.

I have here a piece of apparatus first designed several years ago during my student days. It is a modification of an arrangement devised by Prof. S. P. Thompson, and described in *Stewart & Gee*, 2d vol., p. 160. The one I have here was first suggested to me by Prof. H. S. Carhart, of Michigan University, and has since been somewhat modified by myself. If we take an ordinary slide wire bridge having four openings for coils at the back and (the slide wire being in front) fill these spaces, beginning at the left, with coils designated P R_1 R_2 and Q, respectively, connect the battery from between P and R_1 to between R_2 and Q, and the galvanometer from between R_1 and R_2 to a point on

the slide wire, we have substantially the method which is known as the Carey-Foster method. Designating the resistance of copper connector at the left by r_1 and of copper connector at the right by r_2 and letting P be the resistance of unit division of the wire.

$$\frac{R_1}{R_2} = \frac{P + r_1 + X_1 \rho}{Q + r_2 + (L - X_1) \rho} \tag{1}$$

where X_1 is the reading on the bridge wire and L the total number of divisions. Reverse the position of P and Q and we have

$$\frac{R_1}{R_2} = \frac{Q + r_1 + X_2 \rho}{P + r_2 + (L - X_2) \rho} \tag{2}$$

From (1) we have

$$\frac{R_1}{R_1 + R_2} = \frac{P + r_1 + X_1 \rho}{P + Q + r_1 + r_2 + L \rho} \tag{3}$$

and from (2) we have

$$\frac{R_1}{R_1 + R_2} = \frac{Q + r_1 + X_2 \rho}{P + Q + r_1 + r_2 + L \rho} \tag{4}$$

From (3) and (4) we get

$$Q + r_1 + X_2 \rho = P + r_1 + X_1 \rho$$

$$Q - P = \rho (X_1 - X_2)$$

which is an expression independent of the resistance of the end pieces of the bridge, being merely the resistance of that portion of the wire over which we must move in obtaining our two balances. Thompson's device is merely for quickly and conveniently interchanging coils P and Q; with it we must change the position of four copper connectors in four mercury cups; this is tedious and increases the danger of a change of temperature between the adjustments. The modification which I have here has reduced these changes to two which can be almost instantly made. With this device and a carefully calibrated bridge wire it is an extremely simple matter to attain an accuracy of $\frac{1}{100}$ per cent., while much higher percentages of accuracy may be gotten with care. Of course, in this method the coils P

and Q must be at a definitely known temperature which shall not change during the taking of the two readings; hence, the two coils are placed in well stirred water or oil baths. The other coils R and S are wound together and left in the open air as, if they change at all, they will probably change about equally and the result be of no appreciable importance. This device is also the best thing to use in determining temperature coëfficients of wires; a length of wire is wound up on a spool, immersed in oil at a definite temperature and compared with a standard. The temperature of the oil is then raised and the resistance of the wire again determined; knowing the difference of temperature and the change of resistance the temperature coëfficient follows.

On the VARIABLE ACTION of TWO-COIL SOLENOIDS.

By Wm. S. Aldrich, Johns Hopkins University, Baltimore, Md.

[*Read at the meeting of the Electrical Section, held February 2, 1892.*]

The Two-coil Solenoid Electro-magnetic Mechanism produces a double-acting reciprocating movement of an iron core or plunger, when the coils are variably energized by a pulsating current, causing the induction to rise from zero to a maximum alternately in each coil. The action of the plunger under the influence of the two magnetic fields of force, other conditions being equal, will vary according to whether the two solenoids act with or against each other. The respective movements of the plunger are not only very different in each case, but the maximum pull in either direction towards the central line between the two coils is greater in the former arrangement than in the latter, as will be seen by referring to the plotted results of the experiments under these two conditions.

A preliminary experiment was made with a variable current obtained by an adjustable resistance, to determine the maximum pull, its variation, the movement of the plunger

when under maximum pull, and also when exerting no pull, or when in a position of equilibrium. In the experiments of which the results are shown graphically, the pulsating current was obtained by a rotating brush * moving around the commutator of a dynamo, and the action of the two coils was examined with reference to:

(1) The combination (the differential coil-and-plunger of Sylvanus P. Thompson's classification), consisting of the two solenoid coils as two parts of one coil, traversed by a pulsating current of variable intensity in each part, and giving rise to a resultant magnetic field from the combination of the two variable-intensity electro-magnetic stresses of like character, and constant in direction.

(2) The combination operating as two distinct solenoids, producing resultant stresses in the ether medium from the two variable-intensity electro-magnetic stresses of opposite character and constant in direction.

The Pulsating Current Obtained by Variable Potential through constant resistances, will give quite a steady pull and almost regular reciprocation of the plunger, from the regular variations of potential, and so of current and of magnetizing effect of the two solenoid coils. But, whereas the electrical resistance of the solenoid coils may be considered constant under all ordinary conditions (excepting the slight variations due to the heating effect of the current), the magnetic resistance or reluctance of the iron core is quite variable with the intensity of magnetization. So that while a regular variation of potential may produce a regular undulation of the current passing through the solenoid coils, the resultant effect upon the iron core plunger may vary within wide limits; also, according to the counter-electro-motive force, depending largely upon its speed of reciprocation, and its position in the field of force, which position may be more or less controlled by external mechanical forces.

* As in Van Depoele's double-acting pulsating current electro-magnetic reciprocating mechanism, for claims and applications of which see United States Patents, No. 422,855, of March 4, 1890; No. 458,873, of September 1, 1891; No. 461,294 and 461,295, of October 13, 1891.

The Two-coil Solenoid in these Experiments consisted of two coils, of 200 turns each, of No. 14, B. & S., double-cotton covered copper wire; both coils were wound in the same direction, on a thin brass tube, of 0·625 inch outside diameter, and 4·1 inch long; the coils themselves were each 1·9 inches long, and separated by a 0·1 inch fibre disk, and protected also at the outer ends by 0·1 inch fibre disks. The iron core forming the plunger was 0·5 in diameter, and 2·25 inches long, of soft, slightly annealed wrought iron, capable of carrying about 15,000 lines per square centimetre just below the point of saturation. The construction was not iron-clad. The pull was measured by a sensitive spring balance; and the plunger was nominally at rest when readings were taken—it being in static equilibrium under the action of the spring balance and the electro-magnetic stresses.

Preliminary Experiment; Potential Varied by Resistances, introduced in circuit with the solenoid coils, causing a variable current to be supplied to them, from a constant storage battery supply of twelve ampères and 1·75 volts. The inner ends of the solenoid coils connected to a movable or sliding contact along an adjustable resistance, and the outer ends connected to the outer terminals of this resistance, joining up the two solenoid coils as two parts of one coil, forming a differential coil-and-plunger traversed by a current of variable potential.

(*a*) Sliding contact dividing the adjustable resistances in the ratio of four to four (equally) between the two solenoid coils; maximum *downward* pull, three ounces.

(*b*) In the ratio of five (top solenoid) to three (bottom solenoid); 2·7 ounces.

(*c*) In the ratio of six (top) to two (bottom); 3·1 ounces.

(*d*) In the ratio of seven (top) to one (bottom); 3·3 ounces.

(*e*) In the ratio of eight (top) to zero (bottom solenoid coil cut out); 3·3 ounces.

The 2·25 inch plunger, under maximum downward pull, was almost invariably in one position, during this quarter-cycle of operations; its centre being about 1·725 inches above the centre line of the 0·1 inch fibre disk between the two coils; that is, a little more than half-way in the top coil.

The zero position of the centre of the plunger moved upward 0·95 inch—from 0·075 inch *below* the centre line of the fibre disk between the coils (for the four-to-four combination of adjustable resistances), to 0·875 inch *above* this line, when the bottom coil was cut out. This latter position should probably have been 0·95 inch (which is one-half the coil length of 1·9 inches), above the bottom of the top coil; that is, the plunger in normal position of equilibrium in one or the other coil alone, of about the same length, should be about central with that coil under all ordinary conditions. While, when both coils are equally energized the plunger is normally central between them, for thin separating disks, yet the two coils may be so far separated, longitudinally, that the zero position is more or less indeterminate. Other conditions being equal, the plunger not being exactly central between the two coils, shows that the external resistances introduced were not exactly equal in the four-to-four combination. Sylvanus P. Thompson speaks of the maximum pull of a single coil on a plunger of the *same length* of the coil, as occurring when the plunger is about half-way in; and of the differential action of the two coils in the above case, as being simply due to the difference between the ampère turns of the two separate coils.

Experiments with Rotating Brush Method of producing variation of potential and so of current in the solenoid coils. The diagram of connections is shown in *Fig. 1*. The dotted line connection, with voltmeter in circuit, shows the method by which the distribution of potential around the commutator was obtained, giving what Sylvanus P. Thompson has called the integrated curve of potentials. The ordinates of this curve (shown on line E of the plotted results) at any position of the rotating brush around the commutator, gives the total or integrated potential from the fixed brush terminal up to that point. The machine used in the experiment was a one horse-power motor, separately excited and run as a dynamo, at about 2,600 revolutions per minute (normal speed, 2,750). The equal resistances R' and R'' were introduced in the external circuit, which showed about forty-five volts and eight ampères when the rotating brush

was off the commutator. Owing to small variations in the speed of driving pulley, and slight unsteadiness of the exciting current supplied to the field coils, there were slight variations in the external circuit of the machine. The commutator had forty bars, and readings were taken with the rotating brush successively on each bar.

Two Sets of Experiments were made with this rotating brush combination:

(1) With the two coils of the solenoid operated as a differential coil-and-plunger, of which the results are plotted on *Sheet I.*

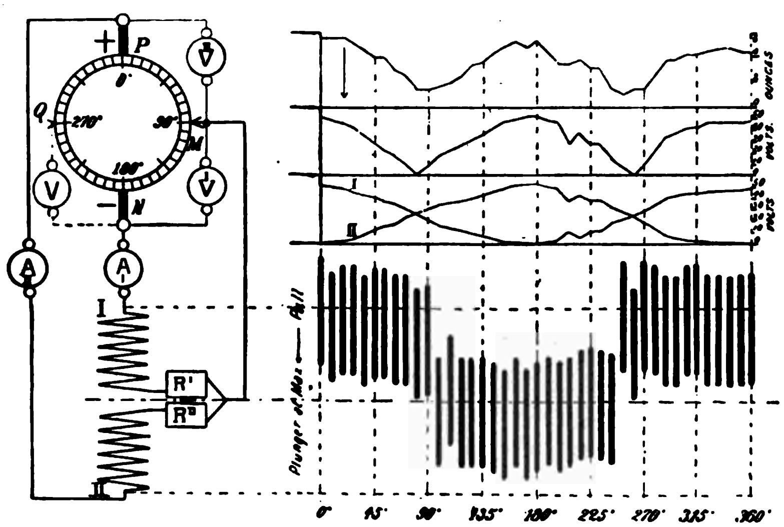


FIG. 1. FIG. 2.

Diagram of connections, and successive positions of plunger.

(2) With the two coils operated as separate solenoids with opposing magnetic fields, of which the results are plotted on *Sheet II.*

The effective ampères, line *B*, and effective volts, line *D*, were obtained for the different points around the commutator by subtracting the corresponding ordinates of the curves on lines *A* and *C*, respectively. The portion of these curves *B* and *D*, on *Sheet I*, between 81° and 261°; and on *Sheet II*, between 72° and 270°—represent negative values, corresponding more or less to the variations of potential and

of ampère-turns chiefly effective in the bottom coil *II*, while the remaining portions of *B* and *D* represent the positive values, which are chiefly effective in the top coil *I*.

The curve on line *E* (the same on each sheet) represents simply the variations of the integrated curve of potentials, when there was no external circuit to the machine.

The curves on lines *F* and *G* represent the paths of the movement of the centre of the 2·25 inch plunger, under maximum pull—the former, *F*, when the maximum pull is upward from bottom coil *II* towards top coil *I*; and the latter, *G*, when the maximum pull is in the opposite direction, from *I* toward *II*.

Line *H* represents the successive positions of the 2·25 inch plunger when in zero position of static equilibrium between the electro-magnetic stresses of the fields of coils *I* and *II*.

The curves on lines *K* and *M* represent the maximum pull in each direction; on *K*, the upward pull, from coil *II* toward *I*; and on *M*, the downward pull, from coil *I* toward *II*.

Fig. 2 shows the movement of the position of maximum downward pull, as indicated on line *G*, of *Sheet I*, the heavy lines diagrammatically represent the successive positions of the plunger.

The Movement of the Plunger is brought about by the effort of its iron core to embrace the greatest possible number of lines of force; and, therefore, so to place itself that it shall have the maximum induction, and shall cause the least deformation of the magnetic circuits. When it is in a zero position between the two coils, it exerts no pull and has no tendency to move into one or the other of the coils; and, if external force is applied to move it out of this position, it will return unto it again when that external force is removed—coming back to rest, as it were, in a position of more or less stable equilibrium. This position falls within the two coils, as an interior position of zero pull; and between it and the exterior positions of zero pull of each coil, respectively, there occur the positions of maximum pull in each direction. These have also a movement, somewhat

similarly phased to that of the zero position. Though the plunger was stationary when readings were taken at each point, it will be seen that the movement of the rotating brush would cause a reciprocating motion of the plunger in a fixed two-coil solenoid. If the plunger is under the action of no external forces, or of balanced external forces, —being then free to move, along with the movement of the position of maximum induction, or position of equilibrium, —it will move more regularly in unison with the rotating brush, when the two coils are operated together as a differential coil-and-plunger (line *H*, of *Sheet II*), than when they are working against each other.

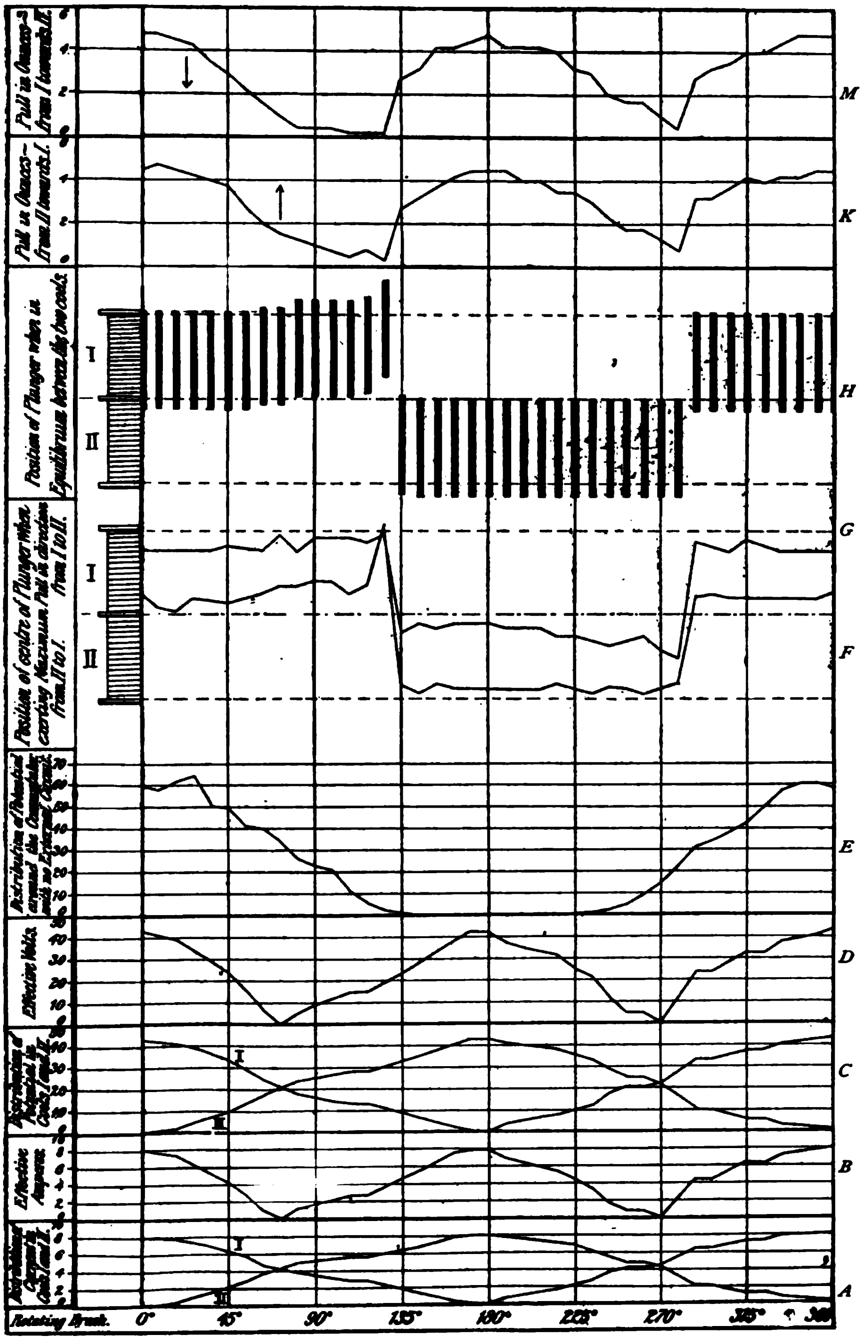
The peculiarity of the second combination is shown on line *H*, *Sheet II*. The position of equilibrium is remarkably steady at each end of the stroke. But just before beginning the down-stroke, from 117° to 135°, it takes a sudden stroke backward, and then very rapidly plunges forward to its new and temporarily settled position of equilibrium, at 135°.

From *Sheet I*, it appears that the plunger passes from one end of its stroke to the other as the effective volts and ampère-turns pass from positive through zero to negative values—corresponding to the resultant induction passing from a decreasing positive to an increasing negative effect on the plunger. But *Sheet II* shows a remarkable displacement of this position of the reversal of the resultant magnetizing effect of the two coils; from 72° the plunger is pushed farther into coil *I*, as its induction decreases while that of coil *II* increases, till the effect of the latter completely overcomes that of the former, and pulls the plunger most completely within its own range of action from 126° to 135°. The reverse operation occurs from 279° to 288° but it is not so marked as in the former.

The movement of these points of zero as well as of maximum pull will be very much affected by the character of the pulsating current supplied to the coils; the counter-electromotive force induced in the solenoid coils, and the variation of this with the rapidity of reciprocation; the character of the return-path for the lines of force, whether

Pull in Ounces—from I towards II.
M
Pull in Ounces—from II towards I.
K
Position of Plunger when in Equilibrium between the two coils.
I
II
H
Position of centre of Plunger when exerting Maximum Pull in direction from I to II. from II to I.
I
II
G
F
Distribution of Potential around the Commutator with no External Circuit.
E
Effective Volts.
D
Distribution of Potential in Coils I and II.
C
Effective Amperes.
B
Distribution of Current in Coils I and II.
A
Rotating Brush: 0° 45° 90° 135° 180° 225° 270° 315° 360°

Jour. Frank. Inst., Vol. CXXXIII. April, 1892. (*Aldrich. Sheet II.*)



through air or iron; and, if through iron, upon how it is disposed, whether in the simple iron-clad construction of an external shell, or in addition to this an internal shell, as in the Ayrton and Perry* tubular iron-clad electro-magnet.

Balance of the Electro-magnetic Stresses of the magnetic fields of the two coils might be effected by a combination which would produce an equal fall of magneto-motive forces at the centre of the plunger, much in the same way as is now done in balancing the Wheatstone bridge, by arranging the resistances of the arms so as to cause an equal fall of electro-motive forces at the terminals of the indicating galvanometer.

But balancing electro-magnetic stresses is a much more difficult and delicate matter than that of the fall of potential in the arms of a Wheatstone bridge. Any application of the principle of this two-coil solenoid in a measuring instrument would require a careful determination of the combined effect of the several variable resistances in the path of the magnetic circuit, chiefly made up of the air-gap resistance and the variable reluctance of the iron core. Also the slightest movement of the plunger into or out of the resultant field of force, of the two coils, produces a variation in the line-integrals of both of these resistances. As it is not possible to eliminate the variation of the magnetic resistance with the variation of magnetization, it is necessary to make the air resistance constant by a fixed air-gap, as in the dynamo.

The Stability of the Electro-magnetic Equilibrium of the plunger, in this two-coil solenoid mechanism, depends upon the way the two coils are operated, whether producing magnetic fields working with or against each other. In the former case the plunger is practically under the influence of one field, having a movable position of maximum induction, whose movement follows closely that of the rotating brush; but if for any one position of equilibrium, the plunger be drawn aside into one or the other

* For this and other typical forms, see Sylvanus P. Thompson's work on *The Electro-magnet.*

coil, and then released, it will slowly resume its former normal position of zero pull; the electro-magnetic equilibrium is stable. In the latter case, however, there is unstable equilibrium of the plunger under the action of opposing electro-magnetic stresses; for a slight movement of the plunger into one of the coils, from its zero position, will so far bring it into the field of maximum induction of that coil, as to cause it to take some new position, where it can best complete the magnetic circuit of that coil under whose influence it is now brought. In stable equilibrium, the plunger is wholly within the range of action of the one magnetic circuit of the two solenoids acting (differentially) as one coil. In unstable equilibrium, the plunger is partly within the range of action of each of the two opposing magnetic circuits, so that almost the slightest movement will send it rushing into the one or the other coil, in order to get into the position where it will have the maximum number of lines of induction passing through it. Moreover, line *H*, *Sheet I*, shows the stable equilibrium to be almost constant in its character; while that of *Sheet II* shows the unstable equilibrium to be variable, from the least instability when the electro-magnetic stresses differ most, at 0° and 180°—to that of greatest instability when these stresses are nearly equal, 45° to 135°, and about 270°.

Industrial Applications of this Two-coil Solenoid Mechanism vary with the character of the work to be done. For pumps, reciprocating machine tools, and like operations, where a steady forward or return stroke, or both, is required, the differential coil-and-plunger of the first combination is most useful. The electro-magnetic stresses are nearly constant, resulting from a more nearly uniform intensity of magnetization of the plunger core, and giving greater maximum pull with less variation than in the second case. For quick-return motion of the plunger, in machine-tool work, the rotating brush may easily be moved around more rapidly in one portion of its rotation than in the remaining portion, giving the plunger a definite ratio of advance to return, as in the Whitworth and other quick-return motions. For electro-magnetic forging, whether by a direct hammer

blow, or by the drop-forging process, riveting, rock drilling, and like operations requiring a definite hammer blow, the two coils may be connected up in opposition to each other, as in the second case. To develop greater power in the one stroke than the other, adjustable external resistances may be used, strengthening one magnetic field and weakening the other to suit the circumstances of the work; and in many cases diminishing the wear and tear on the machine due to the shock of the return stroke. But the loss of current caused by this arrangement may be obviated, by winding one or the other of the two coils in sections connected up in parallel,* so increasing the ampère-turns at either end to any desirable extent.

NOTE.—The author expresses to the following students in the Department of Electrical Engineering his many obligations for valuable assistance: Mr. F. McS. Thomas, for constructing the solenoid mechanism; Messrs. T. M. Brown, W. R. Molinard and J. B. Scott, for arranging the dynamo details; and Messrs. L. M. Aspinwall, H. W. Frye, H. Pattison, A. J. Rowland and R. I. Todd, for observations.

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* The use of regulating resistances and of multiple-sectioned coils in this mechanism are set forth in the United States Patent (Van Depoele), No 422,855, of March 4, 1890.

PROCEEDINGS.

[*Stated meeting, held Tuesday, April 5, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, April 5, 1892.

Prof. Edwin J. Houston, President, in the chair.

Present, twenty members and visitors.

The minutes of the previous meeting were read and approved.

The Treasurer reported the balance in the treasury, and presented bills for lantern slides, printing, etc., which were approved and ordered paid. The Secretary announced the death of Mr. Thomas Hockley, active member, on March 12, 1892, and upon motion the chairman appointed a committee to draft suitable resolutions for the section.

Mr. C. H. Bedell read a paper on "Dynamo and Motor Calculation," with illustrations. Referred for publication.

Mr. Herbert S. Lloyd (visitor) described, with the aid of a working model, a new method of wiring incandescent lights, so that they could be controlled by switches from any number of points, on two or three-wire systems.

Prof. Houston read a letter from Prof. Elihu Thomson, in which the latter described some interesting experiments he had been making with alternating currents of high potential. It was also stated that Prof. Thomson would probably show these and other new experiments before the Section at a future meeting.

There was an informal discussion on the trolley system of electric street car propulsion, and on the conditions under which the passage of an electric current through the body would probably be fatal to life.

Prof. Rondinella proposed to amend Sec. 1 of Art. II of the By-Laws by striking out the word "first" and inserting in its place the word "fourth," making the section read, "The Stated meetings of the Section shall be held on the fourth Tuesday of each month at 8 P. M., except during the months of July and August." (This amendment will come up for action at the next stated meeting.)

The meeting then adjourned. L. F. RONDINELLA, *Secretary.*

PROCEEDINGS.

[*Stated meeting held Tuesday, May 3, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 3, 1892.

Prof. Edwin J. Houston, President, in the chair.

Present, thirty members and visitors.

The minutes of the previous meeting were read and approved.

The Treasurer reported the cash balance in the treasury, and presented bills for printing, which were approved and ordered paid.

One nomination to membership was referred to the Committee on Admissions.

The proposed amendment to the by-laws substituting the word *fourth* for *first*, in Article II, Section 1, so that it reads: "The stated meetings of the Section shall be held on the fourth Tuesday of each month, at 8 P.M., except during the months of July and August," was voted upon and adopted.

This by-law was then temporarily suspended upon motion that the next regular meeting shall be held Tuesday, May 31, 1892.

Mr. Paul A. M. Winand read a paper on "Some Points Regarding Multiphase Current," illustrated by black-board sketches and ingenious working models. To be continued at next meeting, and referred for publication. In discussion thereon, Mr. Carl Hering stated that he thought the term *multiphase* usually applied to currents of two or three phases, and *polyphase* to those of more than three. He and Mr. Wm. S. Aldrich described other diagrammatic methods of representing the variations in alternating currents.

Mr. Carl Hering read a paper on "Ampère-Centimetre: A Measure of Electro-magnetism." It elicited considerable discussion, and was referred for publication.

The meeting then adjourned. L. F. RONDINELLA, *Secretary*.

CONSTANT SHUNT METHOD FOR THE MEASUREMENT OF LARGE CONTINUOUS CURRENTS.

BY CLAYTON W. PIKE.

[*Read at the stated meeting of the Section, held March 1, 1892.*]

The constant, Vienna or Munich, shunt method, as it is variously termed, is something which is by no means novel and is, indeed, well known to some of the section, having been used by them at the Electric Exhibition of the Institute, in 1884. But I believe that the method is not so well known, or at least not so much in use as it should be, and I hope, by calling attention to some of its advantages and by pointing out and showing how to avoid certain errors incident to it, one or two of which are not generally known, to do something toward bringing it into more general use.

For the measurement of continuous currents we have the various forms of ammeter, the Siemens dynamometer, the Thomson platform galvanometers, and the Thomson balances, the tangent sine and cosine galvanometers. With the objections to the ammeters all are doubtless familiar. They are inaccuracy of graduated scale, errors due to residual magnetism or to loss of permanent magnetism, and lack of wide range. The Thomson platform galvanometer does not measure large currents without the use of the permanent magnet which is objectionable if considerable accuracy is desired, and it requires a knowledge of the horizontal component of the earth's magnetism H. The Thomson balance is an instrument of much greater value than the above, being independent of H, having greater range and greater precision, but being even more costly.

The tangent galvanometer requires the value of H, and has only a limited range, which the sine and cosine, though better in this last respect, are tedious to use on account of time required in setting the coils.

The great advantage of the shunt method over all these is that, by the aid of fairly simple and cheap apparatus, currents varying from one to 1,000 ampères or more may

be measured with quickness and a very great degree of accuracy over the whole range.

The shunt method is really a comparison method, and depends upon Ohm's law that the potential difference between two ends of a resistance is proportional to the current flowing through the resistance.

Let *A B* be a conductor whose temperature is kept constant, its resistance will therefore be constant, but need not be known. Pass the current *C*, which we desire to measure through *A B*, there will then be a potential difference *P D* between *A* and *B*..

Let *G* be a mirror galvanometer with telescope and scale, then the deflection *d* is proportional to the current through it, which is proportional to *P D*, as long as resistance of galvanometer and leads is constant, $d_1 \; a \; P\,D_1$ or $d_1 \; a \; C_1$.

Pass any other current C_2 through *A B* then $d_2 \; a \; C_2$ and

$$C_1 = \frac{d_1 C_2}{d_2}$$

If the resistance of the galvanometer and leads be not constant, the algebraical result is less simple and, moreover if the deflections become very large, they are not strictly proportional to the current through the galvanometer which we will call $C g$. Hence the comparison of large with small currents will be somewhat inaccurate. This leads us to a little different method. Place a resistance box *R* in the galvanometer circuit. Pass current C_1 through *A B*, causing a potential difference $P\,D_1$, and sending through *G* a current

$$C_1 \, g = \frac{P\,D_1}{R_1 + g}$$

where *g* is the galvanometer resistance.

Then

$$d_1 \; a \; C_1 \, g \; a \; \frac{P\,D_1}{R_1 + g}$$

or

$$C_1 \; a \; d_1 \, (R_1 + g)$$

in the same way

$$C_2 \; a \; d_2 \, (R_2 + g)$$

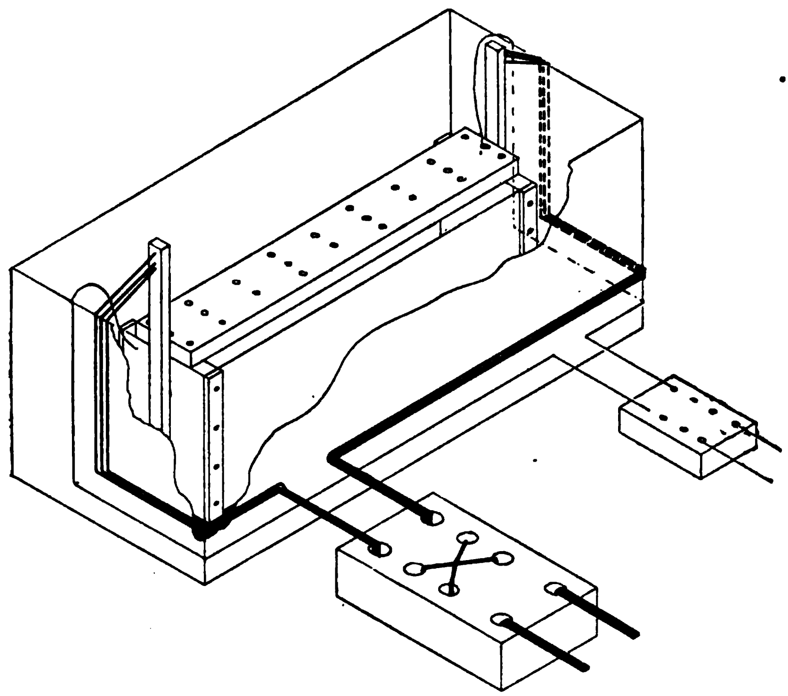
then

$$\frac{C_1}{C_2} = \frac{d_1(R_1 + g)}{d_2(R_2 + g)}$$

or

$$C_1 = \frac{d_1(R_1 + g)}{d_2(R_2 + g)} C_2$$

Now, if when C_2 were flowing we had accurately measured



it by a tangent galvanometer or by the electrolytic cell, the quantity

$$\frac{C_2}{d_2(R_2 + g)}$$

would be known. Call it K the constant of the shunt. Then we have the general formula for the shunt that the current whose value we desire is equal to

$$d(R_1 + g)K$$

Now, by using the resistance box, and by adjusting it to

give about the same deflections on the galvanometer in different measurements we have secured two important advantages.

(1) We have done away with the error of assuming that the currents through the galvanometer was strictly proportional to its deflections.

(2) The resistances R being large in value with reference to galvanometer and leads, and being of platinoid or some metal with very low temperature coëfficient, any change in temperature of galvanometer and leads will produce little effect on the result.

Like all other methods this one is liable to certain errors, some of which I will mention and briefly suggest their remedies. The way in which they affect the result will also be stated.

(1) *Reading of Deflection.*—Suppose you could read to within ·01 cm. on the scale. If the deflection were 10 cm. the error would be

$$\frac{\cdot 01}{10} = 1 \text{ part in } 1{,}000.$$

The error is evidently diminished as we increase the deflection.

(2) *Error Due to Temperature Change of Galvanometer and Leads.*—If these are of copper their resistance would change four-tenths per cent. per degree Centigrade. This correction could be applied, but if the resistance in R is large with respect to g, this correction will be negligible; (2°) then conflicts with (1°), and we must compromise. Suppose $R_1 = 20$ $g = 2$, and temperature rise $= 10°$ C. then the true value of

$$R_1 + g = 20 + 2 + 2 \times \frac{4}{100} \times 10 = 22{\cdot}08$$

and the error in neglecting the

$$\cdot 08 = \frac{\cdot 08}{22} = 1 \text{ in } 275$$

(3) *Error Due to Temperature Change of Box.*—This is ·02 per cent. per degree Centigrade for platinoid coils, and may be

corrected for, or neglected, according to the desired precision of our results.

(4) *Error Due to Determining Constant K.*—The constant is best determined in most cases by electrolytic cells, say three in series. If one has a tangent galvanometer of proper range, 1-5 ampères, and knows H to the desired accuracy this may be used. A Thomson deci-ampère balance would be very convenient for subsequent determinations of the constant, if its readings were known to be correct within the desired degree of accuracy. An error of ·1 per cent in K causes an equal error in the subsequent measurements.

(5) *Error Due to a Rise in Temperature of the Shunt.*—This may be due to two causes: a rise in the temperature of the room, or the heating effect of the current. Both may be obviated by placing the shunt in liquid artificially cooled

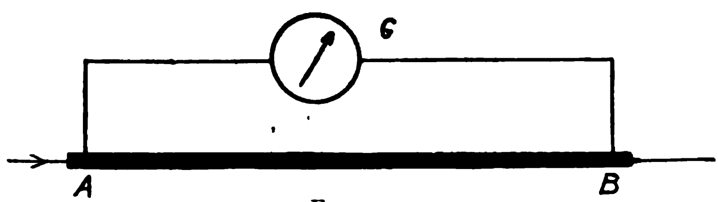


FIG. 1.

by cold water coils, and keeping constant the reading of a thermometer placed in the liquid close to the shunt.

Suppose the rise in temperature were 5° C. If the shunt were of German silver the change in its resistance would be ·04 per cent. $\times\ 5 =$ ·2 per cent. or two parts in 1,000, and the results of the measurement would be in error by this amount. If of platinoid, the error would be but half as much.

(6) *Error Due to Change of Value of H.*—This would be possible if the galvanometer had the earth's field for a resting force. If great accuracy be desired, obtain the value of the constant frequently, and see if it changes. As I have before said a Thomson balance would be most desirable for this, and many laboratories can afford one Thomson balance. Also if we had a galvanometer whose damping could be removed, we could determine whether H had changed by its time of vibration. The sources of

error so far mentioned are well understood and looked out for, but the following are, I believe, not so well known. At least the amount of the effect is not so generally appreciated, and they have, so far as I know, received exhaustive study only at the hands of Mr. W. L. Puffer, of the Massachusetts Institute of Technology. His results are to be found in the *Proceedings of the American Academy of Arts and Sciences*, January, 1888.

(7) *Error Due to Thermo-electric Effects.*—We are obliged to make the resistance of our shunt very low to prevent undue heating, hence the potential differences set up at its terminals are very low. In this case any thermal E. M. F.'s, which might be caused by differences of temperature at the junctions of the different metals, would be liable to affect the readings of the galvanometer. This trouble may be obviated by so making the shunt as to put the junctions under the surface of liquid whose temperature is maintained constant and may be detected by running the galvanometer leads to a mercury cup commutator and testing with reversals.

(8) *Error Due to Electro-chemical Action.*—The shunt is placed in liquid and under the action of the potential differences set up at its terminals there is electrolytic decomposition, (if the liquid be one which can be decomposed as water). This will cause the end having the higher potential to be darkened, owing to oxidization of the German silver by the oxygen set free, while the other end will become whiter or cleaner in appearance, owing to the reduction of the film of oxide on its surface by electrolytic hydrogen. These actions will evidently set up E. M. F.'s, and if the shunt resistance is very low, will cause considerable error in the result. This source of error could be avoided by placing the shunt in some liquid incapable of decomposition with low E. M. F.'s. Chemically pure water would do, but for the trouble of obtaining and keeping it so. Petroleum oils would act slightly on the bare piece of metal composing the shunt, thus producing a battery effect. We must either immerse the bar in some liquid incapable of acting on it or cover the shunt very carefully with some substance not acted upon

by the liquid in which it is placed. Everything considered it seems to me that very carefully covering the shunt with several coats of shellac and afterwards with copal varnish, and immersing it in distilled water would be the most satisfactory method.

Design and Construction of Apparatus.—Suppose we desire to measure currents of from one to 1,000 ampères. This would require a set of five tangent galvanometers of different sizes, the three largest of which would be impracticable. (The diameter of the largest would be about seventy-five feet.) With the sine or cosine galvanometers or Siemens dynamometer we could do better in this respect, but they are still out of the question.

With the Thomson platform or balance we should need three different instruments, which are exceedingly costly.

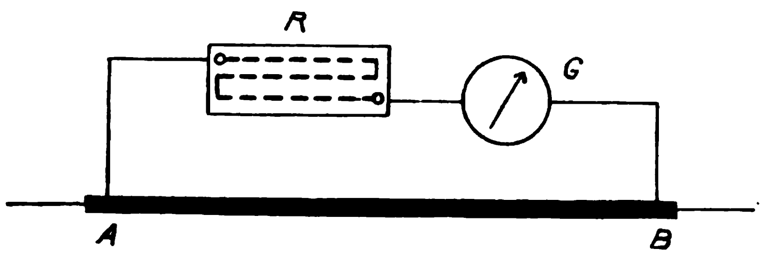


FIG. 2.

Moreover, none of these could be used near dynamos and this means that we must lead the whole of the current we wish to measure perhaps a considerable distance, thus entailing expense for wire and perhaps leakage.

Suppose we make one shunt of resistance ·001 ω. If of German silver 9 inches wide, $\frac{1}{100}$ inch thick, two strips 24 inches long joined in parallel will be nearly the required dimensions. The object of making them so thin is to offer large surface to the water so that they may quickly dissipate the heat produced by the current. The rate of production of heat with the maximum current 1,000, ampères, will be $·24\ C_2 R = ·24 \times 1{,}000^2 \times ·001 = 240$ calories or enough per second to heat 240 grammes of water 1° C. if none of the heat be dissipated. We must now provide a containing vessel large enough to hold so much water that it will not be

unduly raised in temperature, and large enough to admit of placing in it coils of pipe which shall carry cooling water if this be found necessary with the larger currents.

The two German-silver strips should be joined thus by massive cast copper blocks, to which they are carefully soldered. To make the junction doubly secure, thin strips of copper 9 x 1 x ¼ inch are screwed and soldered on over the German silver, as shown. The vertical projecting copper bars *D* and *F* are for connecting the shunt into the circuit where we wish to measure the current.

The arrangement so far described would collapse, owing to the thinness of the German silver. So it is necessary to hold the copper blocks apart at the top and bottom by some arrangement which shall be insulated from the shunt. This can be done by screwing on to both top and bottom of the copper blocks, a piece of board 24 x 4 x 1 inch, as shown in drawing. The board on top should be pierced with a large number of holes, as shown, in order to facilitate the circulation of water. The ends of the boards touching the blocks should be soaked thoroughly in melted paraffin and coated with shellac. The screw holes in the blocks should be filled with paraffin, the screw heads countersunk in the wood, as shown, and melted paraffin poured over them. The whole arrangement should then be coated with shellac and copal varnish *thoroughly*.

The containing vessel may be of wood, paper or galvanized iron, about 32 x 14 x 13 inches. Such a vessel will contain, besides the shunt, about 85,000 grammes of water. Now, the number of heat units, small calories, developed in one second by 1,000 ampères flowing through ·001 ω is in one second as before stated, such as would heat 240 grammes of water 1° C. Hence it would take to heat 85,000 grammes 1°, a time $\frac{85000}{240}$ seconds, or about six minutes, if there were no radiation. But it is probable that this heat produced will not be instantly communicated to the entire mass of water, hence, for the large current measurements it will be advisable to lead coils carrying cold water close to the German-silver strips, both inside and outside, if we desire great accuracy in our measurements.

Galvanometer.—Any form of sensitive reflecting galvanometer which is dead heat and wound with coils of low resistance may be used. If the instrument has the earth's field alone for a restoring force, as is generally the case, (neglecting torsion), it would be convenient to have the

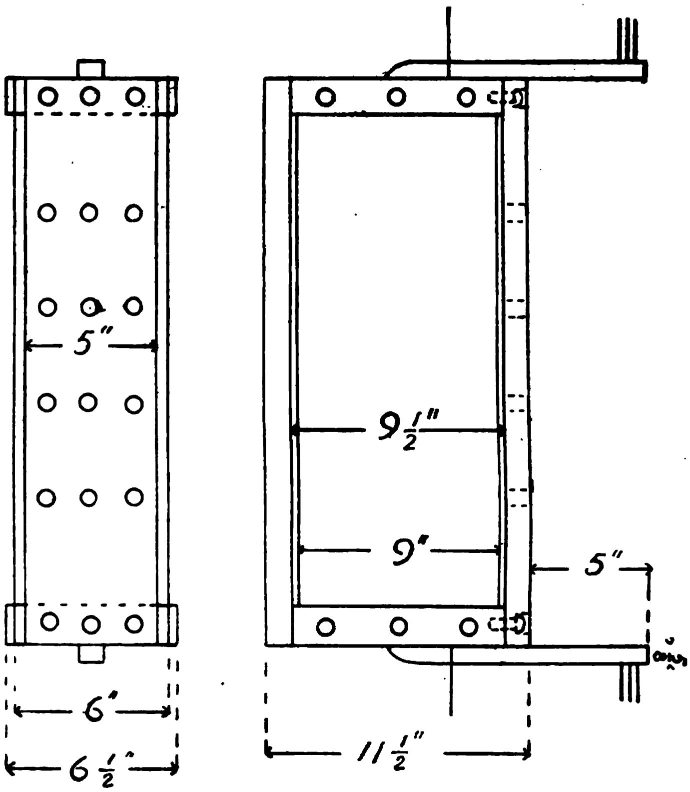


FIG. 3.

damping copper mass easily removable. The following will illustrate the design:

Suppose the scale of telescope is divided into millimetres, and we can read with an error of ·1 mm. by eye estimation, then with a deflection 10 cm. the error in reading would be $\frac{1}{1000}$ = 1 in 1,000. If our scale were distant from mirror of telescope by 1·5 metres, the deflection of the mirror for a reading 10 cm. would be about 2° for $\frac{10}{150} = tan.\ 2\ \alpha = 2\ tan.$

a approximately. $tan.\ a = \frac{10}{300} = \cdot 033$ and a the deflection of mirror $= 1° \ 54'$.

When 1,000 ampères are flowing, the potential difference acting to send a current through the galvanometer is $100 \times \cdot 001$ or one volt. Suppose we put in the galvanometer circuit 10,000 ohms, the maximum of an ordinary box, then the current through the galvanometer will be ·0001 ampères. With sufficient accuracy, we may apply the tangent galvanometer formula,

$$C = \frac{10\ H\ \gamma\ tan.\ a}{2\ \pi\ n}$$

from which we have

$$n = \frac{10 H\ \gamma\ tan.\ a}{2\ \pi\ C} = \frac{10 \times \cdot 2 \times \gamma \times .033}{2 \times 3 \cdot 1416 \times \cdot 0001}$$

Assume a mean radius $\gamma = 2 \cdot 5$ cm., then n the number of turns $= 266 = 41 \cdot 78$ metres or about 136 feet of wire. If we take a copper wire whose diameter bare is ·036 inches the resistance will be about $1 \cdot 1\ \omega$, and the wire will lie in a groove $1 \times \frac{5}{8}$ inch, whose mean radius is 2·5 cm., or about one inch.

When one ampère goes through the shunt the potential difference will be $1 \times \cdot 001 = 1$ volt. Then to give about 10 cm. deflection we should insert such a resistance that the galvanometer current would be ·0001, and this resistance would be about nine ohms. Then should the temperature of the galvanometer coil rise 5° C., the resulting error would be but two parts in 1,000 from this cause alone.

A galvanometer of the D'Arsonval pattern might be used and would have the advantage of being independent of any changes in H, and of being very dead heat. It should be designed with as low resistance as is consistent with the condition that a current ·0001 ampères shall produce a deflection of 2°.

Two commutators are necessary. The larger receives the six coarse wire soldered into the copper lugs $D\ F$ of the shunt, shown in *Fig. 3*. These wires should be No. 0000 B. and S. three in parallel, and the commutator of the mercury cup

variety, so arranged that the shunt can be entirely disconnected from the dynamo circuit.

Into each of the holes at *H* and *K*, *Fig. 3*, should be soldered, carefully, a No. 18 B. and S. copper wire thoroughly insulated, and the joint covered carefully with shellac and copal. These are led out to the small mercury commutator for the galvanometer circuit arranged like the other so that the galvanometer can be isolated from shunt and main circuit. Then any thermo electric or electro chemical effects can be detected and studied. For instance, disconnect galvanometer entirely from commutator and note reading. Connect it to commutator with shunt uncon-

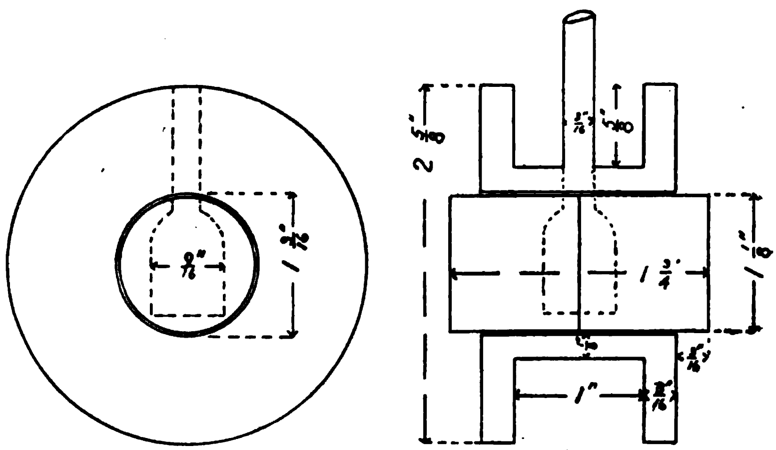


FIG. 4.

nected, and there should be, of course, no deflection even by reversing the commutator. Connect shunt (still with no current in it) to galvanometer commutator, and see if there is any deflection, reversing this time the connection from shunt to galvanometer. Finally, run current through shunt, and see whether changing the commutators produces any change in deflection, being sure that this current is maintained constant. Disconnect shunt from dynamo circuit, and see whether there is any appreciable deflection. The time occupied for these tests is very short, if the commutators are properly arranged, and if the tests show no appreciable thermo-electric or chemical effects, we may feel

sure that our apparatus is satisfactory in this respect. Finally, provide a sensitive thermometer whose range is from about 60° F. to 80° F., or 15° C. to 27° C., and arrange so that it will be placed close to one of the German-silver strips of the shunt. Read when no current is flowing, and then when the maximum current flows. Then if these readings differ 5° C., or 9° F., the error would be two per cent., as previously stated. If greater accuracy be required send cold water through the coils, and read the thermometer, then by sending the water through fast enough, the heating effect of the current may be nullified to the desired extent.

The sketch below shows the general appearance of the completed shunt, together with the commutators.

Recent researches of Prof. Ayrton on the D'Arsonval galvanometer indicate that such a type wound with plati-

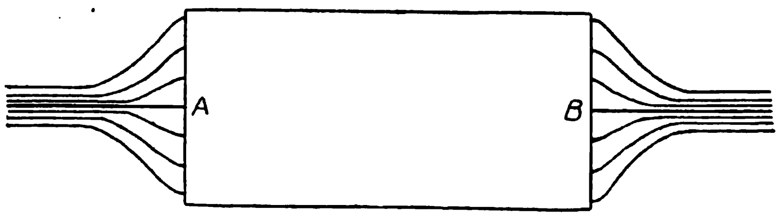


FIG. 5.

noid with phosphor-bronze strip suspensions would be most desirable, and, therefore, the following arrangement commends itself, more especially where the field around the galvanometer is subject to fluctuations. Use for the shunt bar a sheet of platinoid, to which the wires carrying the main current should be soldered. Preferably there should be several such wires soldered on the end edge of the sheet and distributed at equal distances along the edge so as to secure uniform distribution of current in the strip. *Inside* at the points *A* and *B* the leads (of platinoid) to the galvanometer commutator should be fastened. If then a D'Arsonval, made as above and having its telescope and scale rigidly attached to itself, be provided, it may be used where the other arrangement would be out of the question, namely, near the dynamo room. Moreover, by making everything of platinoid, we have done away with temperature correc-

tions, provided the platinum strip be of such dimensions that the maximum current doesn't heat it appreciably. The strip then may be kept in air, the only danger being a greater liability to thermo-electric effects due to differences in temperature at the junctions, and this can be tested by commutation.

Using the D'Arsonval, we can get a greater deflection for a given potential difference at its terminals, therefore, the resistance of the strip may be made lower and less energy be used up in the method of measurement, and in some cases this is an important advantage. On the other hand, since we measure with smaller potential differences, any thermo-electric effects will produce a greater error in our results.

CEREBRAL RADIATION.

BY PROF. EDWIN J. HOUSTON.

[*Read before the Electrical Section, March 1, 1892.*]

GENTLEMEN: I have thought it possible that it might interest you to consider some rather wild speculations in which I have indulged for a number of years past, but which I have heretofore refrained from publishing. In these speculations, to which I was first led by a suggestion from a friend, I have endeavored to correlate, to some extent, the phenomena of thought with grosser physical phenomena. Although the suggestions I have to offer as a basis for a hypothesis of the mechanism of cerebration, are confessedly incomplete, and, perhaps improbable, yet I have concluded to place them on record as of possible interest to the scientific world.

I am, of course, aware of the fact that the psychical operations of the brain are by no means understood. It is generally believed, however, that the seat of psychical activity is the cerebrum. The manner in which the brain acts to produce, record, and reproduce thought is unknown, and will probably remain unknown.

On the single assumption, however, that cerebration or thought, whatever may be its exact mechanism, is accompanied by molecular or atomic vibrations of the gray or other matter of that part of the brain called the cerebrum, I would propose the following hypothesis to account for telepathy, mesmerism, thought transference, hypnotism and other cognate phenomena.

Postulating the existence of the universal or luminiferous ether, which is now generally accepted in scientific circles, and bearing in mind the fact that this ether passes through even the densest matter, as easily as water through a sieve, it follows that the brain atoms or molecules that are here assumed as the cause of cerebration, are completely surrounded by the ether. Now, since the ether is a highly elastic, easily movable medium, it would follow that thought or cerebration, if attended by vibrations, must necessarily develop in the ether wave-motions, which have the brain atoms or molecules for their centres. In other words, the act of thought or cerebration necessitates an expenditure of energy, because it necessitates the setting in motion of these assumed atomic or molecular brain particles.

The exact nature of the motions that are assumed to attend an active condition of the brain must necessarily remain unknown as long as we are ignorant of the exact nature of the mechanism that is moved. But, if an active brain evolves thought because something is set in motion, it, of course, follows that a brain absolutely free from producing thought must be at rest so far as that kind of motion is concerned. An absolute freedom from thought in a healthy brain is most probably a condition that seldom exists; relative rest, however, must be quite common.

That the brain cells, of the gray or other matter involved in the production of thought, can be caused to assume certain groupings or relations towards one another would appear to follow from the ease with which that curious function of the brain called memory, permits it to readily recall past peculiarities in the to-and-fro motions. By continually repeating certain trains of thought, as in study or repeated observations, the peculiar motions required to pro-

duce such thought are probably given a set or tendency to form more or less permanent groupings. When, therefore, the brain is moved or played upon, so to speak, these motions recur and certain memories are awakened.

How may these motions be produced? The answer would certainly appear to be both from within and without. It is, perhaps, possible that the flow of blood to an active brain, which as is well known attends all active cerebration, is not only for the purpose of nourishing and rebuilding the organ, but also for affording the purely mechanical force, that needs but to touch this marvellously attuned organ to awaken the thoughts already impressed thereon, or to sit in judgment on new combinations never before presented to it.

I will suggest an explanation later on as to how these impressions may possibly be excited from without.

Whatever be the origin of these vibrations, or, however, excited, energy is required to be expended in producing them, and as the brain-worker will readily acknowledge, the expenditure of such energy often calls for an enormous expenditure of nervous force.

Cerebral energy, or energy thus expended in producing thought, is dissipated by imparting wave motions to the surrounding ether, and such waves are sent out in all directions from the brain, possibly in greater amount, or of greater amplitude from some of the brain openings, as, for example, those of the eyes.

Although there are no absolute proofs of the existence of the molecular or atomic vibrations of the brain particles which I have assumed, such a movement, however, is far from being improbable, and, indeed, some facts known to the medical profession are far from being at variance with such an assumption. A certain amount of pressure on the brain arising from the pressure of the blood is necessary for its proper action. If this pressure increases beyond a certain value, as, for example, in cases of fractures of the skull, where a portion of the bone is depressed by the fracture, thereby producing a compression on the brain material, all thought or cerebration instantly ceases; but when this

pressure is relieved, by the act of trephining, cerebration not only begins, but curiously enough, generally goes on from the point where the patient left off, when the injury occurred.

Let us assume, then, that cerebral radiations or waves are given off from every sentient or active brain, and that these waves pass into the space around the brain something like the waves that are imparted to the air around a sounding tuning-fork.

The cerebral radiations are not so gross as those of sound. Their wave-lengths are almost certainly much shorter. They are imparted to the universal ether.

If such waves, which I would call thought-waves or cerebral-waves, be present in ether that fills all space, it will be interesting to inquire what phenomena they might be expected to produce.

It being assumed that these vibrations take place in the ether itself, there need be no doubt or speculation as to the general nature of the waves themselves. They would presumably partake either of the nature of transverse or torsional vibrations.

The commonest character of the vibrations which occur in the universal ether are the vibrations which are now generally recognized as transmitting the phenomena of heat, light, electric or magnetic radiations; viz., of transverse or torsional vibrations.

An active brain may, therefore, be regarded as moulding the ether around it into thought-waves, that are spreading outwards from it in all directions. In this respect, it is not unlike a conductor through which an oscillatory discharge is passing, producing those waves which Hertz has so beautifully demonstrated as resembling the vibrations that produce light.

Assume, then, that the cerebral radiations partake of the nature of thermal, luminous, electric or magnetic radiations, and the following explanation of telepathy, or thought transference, is, to say the least, not improbable.

I would explain the possibility of the transference of specific cerebral vibrations from an active brain, to a passive

or receptive brain, by the simple action of what is known in science as sympathetic vibrations.

Take the case, for example, of a vibrating tuning-fork, that is sending off its waves across the space which separates it from a second tuning-fork, not as yet in motion, but tuned so as to be able to vibrate in exact unison with it. As is well known, the exact correspondence between the period of the active, or the transmitting-fork, and the passive- or the receptive-fork, is such that the vibrations of one fork are gradually taken up by the other fork, so that the energy of the motion of the one is transferred or carried across the space existing between them, by means of pulses or waves, set up in the air which surround them.

As is well known, such sympathetically excited vibrations can be produced in a fork situated at a considerable distance from the exciting-fork.

Or, similarly, take the case of the sympathetic vibrations excited by waves of light. Solar energy is radiated or transferred across the space existing between the sun and the earth by waves or oscillations in the luminiferous ether. These waves, falling on the delicate structure of a leaf, suffer a species of selective absorption, certain wavelengths being absorbed and others thrown off. The absorbed waves excite or produce sympathetic vibrations in the molecules of carbon dioxide present in the leaf, and cause the atoms of carbon and oxygen in such molecules to move towards and from one another in interatomic vibrations, which increase in amplitude or violence until their chemical affinity or atomic attraction is overcome and dissociation occurs. The oxygen is then thrown from the leaf into the air, and the carbon is retained in the structure of the plant.

Or, take the still more interesting case of what Hertz calls electric resonance. As already mentioned, it is now generally recognized by electricians that a conductor, which is the seat of an oscillatory electric discharge, is sending into the space around it electric waves or oscillations which travel with the velocity of light, and which are in fact of exactly the same nature as light itself. If

these electric waves meet a circuit so tuned as regards the period of oscillation of the circuit in which they originally occurred, as to be in consonance with them, electric oscillations will be set up in this circuit, of exactly the same nature as those exciting it.

In view of these facts it does not seem improbable to me, that a brain engaged in intense thought should act as a centre of cerebral radiations, nor that these radiations proceeding outwards in all directions from such brain should affect other brains on which they fall, provided, of course, that such brains are tuned to vibrate in unison with them. In such cases the absorption of energy by the recipient brain may be either a species of selective absorption, in which its train of thought is only modified, or it may be absolute, in which case the recipient brain has excited in it an exact reproduction of the thoughts of the exciting brain.

Such a hypothesis is far from improbable; on the contrary, it would appear to be supported by a variety of curious circumstances, which have only wanted some general hypothesis to properly correlate them.

If such a hypothesis be true, then these cerebreal vibrations or radiations must travel through space with exactly the velocity of light. This is of course on the assumption that the vibrating or oscillating brain molecules or atoms set up vibrations similar to those of light. Of course, this equality between the velocity of cerebral wave propagation and that of light is true only for free ether. In the ether which fills the interatomic of intermolecular spaces of gross matter, or, as it is technically called, combined ether, the velocity of wave propagation varies according to the particular character of the matter with which it is associated. A retardation or decrease in the velocity of the assumed cerebral waves would doubtless be experienced while passing through the materials of the skull and head.

If thought travels along waves in the ether similar to waves of light, it would be able to travel along any path by which rays of lights cax pass. It can therefore travel along rays of light, *i. e.*, along paths in the ether through which rays of light are moving.

There is a well-known experiment in hypnotism, in which the patient, placed in a state of semi- or complete unconsciousness, has his brain called into a more or less active condition by the suggestions of the hypnotizer, which might seem to somewhat favor the hypothesis of cerebral radiation.

It might be interesting, in view of the above suggestions, to see whether a hypnotizer, placed in such a position as regards the hypnotized that flashes of light falling on his eyes shall afterwards fall on the eyes of the patient, to observe whether or not acts of suggestion are more readily perceived by the brain of the hypnotized along such rays of light than without the aid of such rays.

If the preceding speculations be regarded as wild, and that this is true I have already granted, what may not be said as to the following?

If thought radiations partake of the nature of ether-waves, then there should presumably exist in the thought radiations or waves, phenomena corresponding to the various phenomena of thermal, luminous, electric, or magnetic radiation; even the phenomena of reflection, refraction, and possibly even of dispersion of such waves, would appear to be a possibility. In this connection, it is of interest to imagine the analysis or separation of a complex wave of thought into its component or elementary waves, corresponding to the separation of a beam of light, by means of a prism.

In this connection, there would be a new significance in the phrases, "radiant with thought," or, "to concentrate one's thoughts on a subject."

If thought radiations or waves partake of the nature of light, then it would seem among the remote possibilities of science—to obtain, say by means of a lens—a photographic impression of such thought-waves on a suitably sensitized plate, somewhat after the manner of the ordinary photographic picture. Such a thought-record, suitably employed, might be able to awaken at any subsequent time in the brain of a person submitting himself to its influences, thoughts identical to those recorded.

Of course, I am aware of the improbability of such a

record being obtained in the near future, and of the exceeding difficulties that would seem to stand in the way of ever obtaining it.

Until we know something more definite concerning the nature of these assumed cerebral vibrations and of their lengths, we must necessarily be seriously handicapped as how to best permanently fix them on a suitable record-surface, and how afterwards to cause such record-surface to interpret its peculiarities to the brain. I merely throw it out as a possibility of what science may have in store for those who come after us. I would suggest, in this connection, that 100 years ago it would probably have been regarded as quite impossible that the telephone or the phonograph could have been produced.

Such a thought-record, however, if obtained would not be an image of the thought itself, or of the particular groupings of the particles, whose to-and-fro movements attend or produce thought, any more than the tracings of the phonograph record form an image of the spoken words. They would merely represent the to-and-fro motions of the ether set in motion by the thought or cerebrations.

An eye looking at such an image would not be influenced thereby. If, however, ether waves similar to those recorded could be reproduced by causing light to pass through such photographic images of the to-and-fro motions of thought-waves, such waves might be caused to influence the brain and thereby awaken thoughts similar or identical to those recorded.

I have often amused myself with picturing a possible thought-recording machine, whereby the thoughts of an active brain might be recorded continuously and permanently on a moving sensitized film, the exposed surface of which was placed at the focus of a large lens placed in front of any one engaged in intense thought.

If, like the cylinder or plate of a phonograph or gramophone, such a record were afterward rotated at the same speed as that at which it received its impressions, under circumstances in which light passing through it is moulded into waves similar to those recorded on it, such waves when

caused to act on a receptive brain, should, it would certainly seem, excite therein thoughts identical to those recorded as its record-surface.

Of course, it is needless for me to say that such a machine has never been actually constructed and is still as unsubstantial as are the speculations which I have offered you. Indeed, the probabilities against its being produced are so great that I have hesitated even to mention it.

Some experiments might be tried in a similar manner in thought transference, by holding large lenses in front of the eyes of a hypnotizer at such a distance as to converge the assumed cerebral radiations on the eyes of the hypnotized. These experiments might be tried either along with light, or independent of it.

I know that many points of the hypothesis which I have suggested are quite improbable, and that I may and probably will be misunderstood by some as putting forward facts rather than a bare hypothesis.

Probably one of the most serious objections to the hypothesis is to be found in the fact that the phenomena of telepathy and thought transference are not of more frequent occurrence. This I must frankly acknowledge to be a most serious objection. I would suggest, however, that the comparative infrequency of the phenomena may possibly be explained by the presence in the human body of a shield which protects the brain or the nerve centres from the effects of cerebral radiations. It is not impossible the sheathes of the nerves act as screens to prevent the reception by the brain of these thought radiations.

Prof. Tyndall, in his work on sound, alludes to the well-known fact that when sympathetic vibrations are being excited by a sounding tuning-fork in any body near it, that there is a greater rapidity of expenditure of energy of the fork's motion than when it was not exciting such waves. The analogue of this phenomena exists, perhaps, in the case of the assumed thought transference. Mental energy is presumably expended at a greater rate when it is exciting thought-waves in this manner, than when such are not being excited.

There has often been experienced by me as a teacher a feeling of great exhaustion in taking charge of or watching a room in which a number of bright students were undergoing an examination. It is possible that the cause of this exhaustion is the rapid dissipation of energy by the cerebral radiations being absorbed by the receptive brains of the examinees. I am informed by certain physicians, that a feeling of great exhaustion is experienced by them in the treatment of some cases.

If there be any truth in the hypothesis I have briefly outlined, there should be what I would term a kind of vital radiation going on and passing outwards from the body of a healthy person, which may not improbably excite by sympathetic vibrations in the bodies of weaker persons around them, vibrations of a normal or more healthy type than those present in the sick person.

If this be true, the old belief of the efficacy of the laying on of hands, or of magnetic healing, may find some foundation, in fact, apart from what is most probably the general explanation of such causes, viz., hysteria.

I have thrown out the above hypothesis of cerebral radiations with considerable doubt and hesitation as a suggestion only to those working in the field of telepathy or thought transference, in the hope that I may thereby call the attention of such investigators to some phenomena in this very obscure field of research.

DYNAMO AND MOTOR CALCULATION.

By C. H. Bedell.

[*Read at the stated meeting of the Electrical Section, April 5, 1892.*]

In the calculation of the different parts of a dynamo or motor, the work is of course divided into the calculation of the armature, and that of the field; but as the capacity and smooth operation depend principally upon the construction of the armature, it should be worked out first. This work is best divided into two parts; and since the dynamo is

primarily a generator of E. M. F., the first consists of the calculation of those parts which affect the generation of the E. M. F., and the second in proportioning the parts that they will stand the currents which may be allowed to flow.

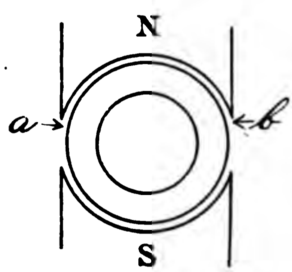
The part of the work which I wish now to consider, is that of the generation of the E. M. F.

For this, one must know to what extent the proposed field will saturate the armature core, since the E. M. F. is generated by the wires of the armature cutting the lines of force which the field causes to pass through the armature core.

One definition of a unit of E. M. F., is that E. M. F. generated by a conductor cutting one line of force once a second. Broadly the E. M. F. generated = lines of force cut $\times$ number of times they are cut per second. The E. M. F. is consequently proportional to the number of lines of force cut, and also the rate at which they are cut.

The rate at which the lines of force are cut is easily obtained, for the total number of conductors on the surface of the armature T, multiplied by the revolutions per second R, gives the number of conductors which cut the lines of force in a second, or the rate per second.

The number of lines of force cut is obtained by multiplying the number of square inches of iron in the cross-section of the armature core C, by the number of lines of force which is known will produce the desired degree of saturation L. Knowing the rate of cutting, and the number of lines of force, we have then the E. M. F. (in absolute units)



$$= T \times R \times C \times L,$$

or

$$\frac{E.\,M.\,F.}{10^8} = \frac{T \times R \times C \times L}{10^8} = \text{volts.}$$

This equation has only one factor about which there can be any uncertainty, which is the factor L; but as a very slight acquaintance with the form of dynamo to be constructed, or a careful calculation of the magnet circuit, will

give the possible degree of saturation, there can be said to be very little uncertainty even in this factor.

The most satisfactory degree of saturation of the armature core, is with 90,000 to 100,000 lines of force per square inch of iron in the cross-section of the armature core, which can be obtained with the usual percentage of watts used in the field.

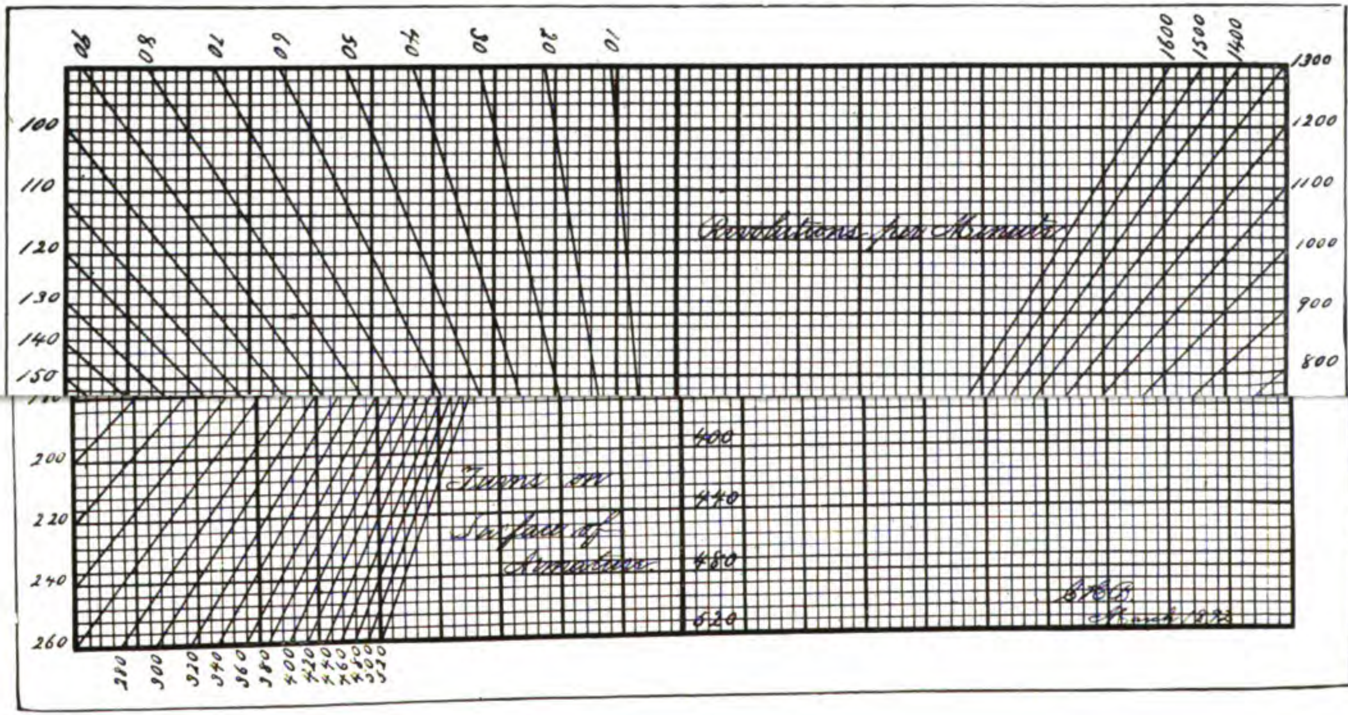
The annexed chart will greatly facilitate this calculation. It is of the same general plan as Mr. Carl Hering's wiring charts published in his *Wiring Computer*, and is used in the same manner. The interpolations for values between the diagonal lines are different in this chart, as the readings in the upper left-hand field should be along a horizontal line, and those in the upper right-hand, and in the lower left-hand field, should be along vertical lines.

It will be noticed that although the chart covers all the usual sizes of generators, yet calculations can be made with it far beyond its limits, as the different factors are so related to each other that where one is changed another can be changed porportionately, except in the case of lines of force per square inch. In the case of lines of force per square inch, values cannot be obtained higher than 100,000 lines per square inch with economy, on account of the iron being saturated at about that point.

If higher values of E. M. F. are desired than those given, the figures in the scale of E. M. F. can be doubled, provided any one of the others, except the lines of force per square inch, is doubled also.

Or if very low values of E. M. F. are desired, the scale of E. M. F. can be divided by any factor, provided any one of the other scales be divided by the same factor.

As an illustration of the use of the chart, let us suppose we have a dynamo having 200 times on the surface of the armature sixty square inches of iron in the cross-section of the armature core, and we desire to know at what speed it will be necessary to run the armature to generate 200 volts. Starting at the 200 point in the column marked "E. M. F. generated," follow the line to the left until it intersects the line representing 200 turns; then follow the


Revolutions per Minute
Turns on Surface of Armature
100
110
120
130
140
150
200
220
240
260
1300
1200
1100
1000
900
800
1600
1500
1400
400
440
480
520

vertical line from that point until it intersects the line representing sixty square inches cross-section; then follow the line to the right until it intersects the line representing the probable degree of saturation, which in this case we will say is 100,000 lines of force per square inch. The speed line which also crosses at this point is the speed required, and is exactly 1,000 revolutions per minute. If only 90,000 lines of force per square inch could be obtained, the speed required would then be a little over 1,100 revolutions per minute. It will be noticed that the form of the armature, amount of active wire, or volts per foot of active wire, do not enter into the calculation. In this method the number of lines of force which pass from any one pole into the armature core and the rate which the wires cut these lines of force form the basis of calculation.

The maximum $P_1 D_1$ is between two points on the armature wire which just include all the lines of force which pass through the armature, to or from any one pole, as at *a* and *b* in the figure, if we are working with the lines which pass from the north pole.

As far as the E. M. F. generated between *a* and *b* is concerned, it makes no difference in a ring armature what becomes of the lines of force after they pass those points, or what the other wires on the surface of the armature are doing. In a two-pole field the other portion of the armature wire, passing under the south pole, cuts the same lines of force, and consequently the same number, and since the rate of cutting them is the same, the E. M. F. generated is exactly the same as that generated under the north pole. But as these two E. M. F.'s are in opposite directions no current flows around the armature, although the points of greatest $P_1 D_1$ are joined together by the parts of the armature wire not under the poles.

Since what becomes of the lines of force after passing the points *a* and *b* of a ring armature, or what the armature wires not between *a* and *b* are doing, makes no difference to the E. M. F. generated between *a* and *b*, the lines of force may be divided so as to pass from the armature into different poles, and the armature wires not between *a* and *b*

may pass under any odd number of poles, and may generate under those poles different E. M. F.'s from those under the pole first considered. It is usual, however, to so build the different portions of a multipolar field, that the E. M. F. generated under the poles is the same in amount, in order that all the terminals of the same potential may be joined together, thus connecting the different portions of the armature in parallel.

The methods of calculation given above, either by formula or chart, deal with the generation of the E. M. F. under one pole only, and consequently can be used for any direct current dynamo having a ring armature, whether for bipolar or multipolar fields.

In the case of drum armatures the conditions are a little different, as the return portion of a wire under the north pole passes under the south pole and generates an E. M. F. which is added to that generated under the north pole, increasing the E. M. F. between *a* and *b*. But the adjoining wire does not give its E. M. F. to *a* and *b*, but to corresponding points adjacent to the south pole. Consequently, it may be considered that the one wire offsets the other, and the same formula and the chart hold good for drum armatures also.

In cases of multipolar machines having the E. M. F.'s generated under like poles in series, the E. M. F., either of formula or chart, should be increased in proportion to the number of such poles.

The square inch of iron in the cross-section mentioned above has reference to the iron in the cross-section through which the lines of force pass from any one pole.

The E. M. F. generated may be that of a dynamo, or that of a motor in the form of counter E. M. F. In each case allowance should be made for the loss in voltage due to the resistance of the armature, and also to whatever loss of E. M. F. there may be due to the lead of the brushes.

PROCEEDINGS.

[*Stated meeting, held Tuesday, May 31, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 31, 1892.

Prof. Edwin J. Houston, President, in the chair.

Present, twenty-two members and visitors.

The minutes of the previous meeting were read and approved.

The Treasurer reported the cash balance in the treasury, and presented bills for printing and lantern slides, which were approved and ordered paid.

The Committee on Admissions reported one election to membership since last meeting.

Mr. E. G. Willyoung described a series of experiments to determine the disturbing magnetic effect of so-called non-magnetic substances in sensitive measuring instruments. Out of a large list of substances experimented with, glass and paraffine were the only entirely non-magnetic ones.

Prof. Edwin J. Houston read a paper describing two methods of obtaining "A Graphic Representation of the Magnetic Field," illustrated by photographic prints and lantern slides. Referred for publication. In discussion thereon, Prof. Rondinella described two other methods that he had used for obtaining similar permanent records.

Mr. Carl Hering stated that he thought the iron filings method misleading, as in the strongest parts of the field the filings were often bunched in one spot, leaving another adjacent to it entirely bare. He preferred the method of investigating a magnetic field by means of a small freely-suspended magnet.

Prof. Edwin J. Houston read a paper on "The Physiological Effects of Alternating Currents of High Frequency." Referred for publication.

Mr. C. W. Pike described "The Disturbing Effects of External Magnetization upon the Weston Measuring Instruments." Referred for publication.

The meeting then adjourned.

L. F. RONDINELLA, *Secretary.*

EFFECT OF EXTERNAL MAGNETIC DISTURBANCES ON WESTON INSTRUMENTS.

CLAYTON W. PIKE,
Dept. Mechanical and Electrical Engineering, University of Pennsylvania.

[*Read at the meeting of Electrical Section, held May 31, 1892.*]

The Weston instruments are slight modifications of the well-known D'Arsonval galvanometer. In the voltmeter we have a pivoted fine wire coil turning between two poles of a permanent magnet, the restoring force being a pair of watch springs.

The action is as follows: When the terminals of the coil are connected to the points whose potential difference we wish to measure, a current flows through the coil proportional to this P.D. This current sets up lines of force and these acting upon the lines due to the permanent magnet cause a force which deflects the needle. It is evident that anything which permanently or temporarily changes the number of lines of force passing through the coil due to the permanent magnet will make the reading different from what it should be for a given P.D. at the terminals of the coil.

Owing to the difficulty of maintaining constant the strength of a powerful magnet, Mr. Weston employs a comparatively weak one, and hence we should naturally expect that comparatively small magnetic disturbances would affect the instrument.

In fact, the earth field exerts an appreciable influence and this fact is taken account of in the calibration of the instruments, although for commercial work the effect is too small to be of any account.

The effects to which I desire to call attention are those of the commercial or workshop order.

In many tests such as determination of the characteristic curve of a machine, the resistance of armature or fields, coëfficient of magnetic leakage, etc., two instruments are employed and the question comes up, how far apart must we put the two instruments so as not to affect each other appreciably.

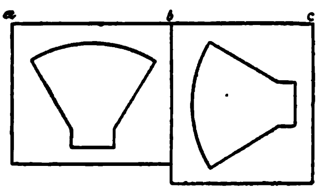
One of my students, Mr. J. A. Stewart, has made at my suggestion some quite extended experiments upon this point and finds that:

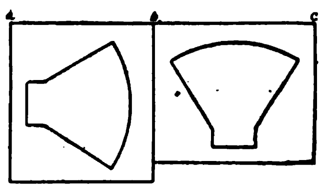
(1) A Weston instrument placed close to another may change its reading by about five per cent. The matter is then worth investigating.

(2) That as far as its disturbing influence goes, it makes practically no difference whether the disturbing instrument has current through its coils or not.

(3) That two instruments placed a foot apart from each other in any position do not affect each other's readings by one-fourth per cent.

It is often convenient, however, if one person is reading both instruments, to have them as close as possible, and Mr. Stewart showed that the best position was either of these two.

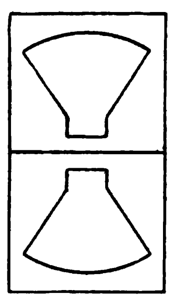




It is best that the points *a b c* should be in the same straight line.

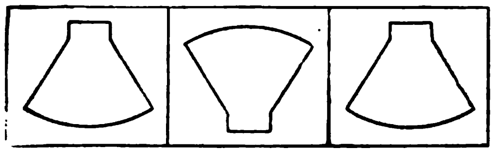
When this is the case neither instrument affects the reading of the other by as much as one-fourth per cent.

The maximum disturbance of five per cent. was reached as would be expected in this position.



We next wanted to find what effect would be produced by some things liable to occur in a workshop.

An ordinary twelve-inch file was placed in different position near a Weston instrument while measuring about half the amount possible. The file, when every part of it was at least four inches distant, produced practically no effect, but when placed thus, changed the deflection over four per

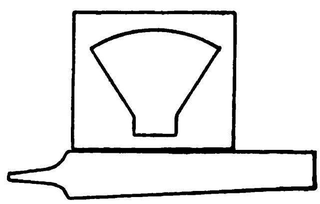


cent. An ordinary bench vise also acted just like the file, having no effect at four inches, but introducing an error of four per cent. when placed in position where it had its maximum effect.

The reason for this action is clear. Take the case of the file above. It evidently leads away from the coil a part of the lines of force due to the permanent magnet. There is then not so strong a deflecting force, and the reading is too small.

As to the effect of very powerful magnets, as those of a dynamo, we have not made sufficient experiments for publication.

Once in a while it is convenient to place three instruments together, and this arrangement gives an error of less than one-half per cent.



The observance, then, of very slight precautions, will allow us to place our instruments in any desired proximity without vitiating, to any appreciable extent, our results.

AMPÈRE-CENTIMETRE, A MEASURE OF ELECTRO-MAGNETISM.

BY CARL HERING.

[*Read at the meeting of the Electrical Section held May 3, 1892.*]

It appears from the following deductions that an electric current multiplied by the length of the circuit will represent the number of magnetic lines of force generated by this current, or, in other words, that the number of lines of force generated by a current can be measured by the product of the current and the length of its circuit. A unit current passing through a unit length of circuit, appears to generate a certain fixed and constant number of lines of force, This, of course, has reference to the electro-magnetism of the current itself and does not include the influence of any magnetic bodies in the neighborhood.

First of all it is necessary to show that ampères multiplied by length will give a unit of a similar nature to magnetic lines of force or flux, in order to show that an equivalent between the two may be given without transgressing the laws of physics. This may be shown conclusively by the aid of the dimensions of these units in the absolute system. The dimension of current is $m^{1/2}\ l^{1/2}\ t^{1}$, while that of magnetic flux (that is, number of lines of force, not their density per square centimetre usually represented by H or B, nor the intensity as it is sometimes called), is $m^{1/2}\ l^{3/2}\ t^{-1}$. It will be seen that the former multiplied by a *length* gives the latter. This shows conclusively that ampère-centimetres, or ampère-feet and magnetic flux are units of the same kind and can therefore be equalled.

Having determined this point, the following appears to show that every unit length of a circuit conveying one ampère, generates a fixed and constant number of lines of force. Using absolute units, the intensity of magnetization (or number of lines per square centimetre) at the centre of

a circle of one turn, according to the well-known formula, is

$$H = \frac{2c\pi}{r}$$

in which r is the radius in centimetres and c is the current.

Now, the intensity of the field is different in different parts of the area enclosed by the circle, being greatest nearest to the wire, but it may be assumed that in all circles, large or small, the ratio of the intensity at the centre, to the average intensity in the whole circle, is a constant. Let this ratio be called K, then the total number of lines will be equal to the intensity at the centre multiplied by the area, and by K; that is,

$$M = \frac{2c\pi}{r} \times \pi r^2 \times K = 2c\pi^2 rK$$

By dividing this by the circumference will give the number of lines per unit length of the circuit

$$2c\pi^2 r K \div 2\pi r = C\pi K$$

or per unit of current, this is equal to π K. It will be seen that this is a constant and is *independent of the radius r*. This means that the number of lines per unit length and per unit current is the same for all circles, and therefore also for a straight line, which is a circle of infinite radius.

From this it appears that, knowing this constant number of lines per ampère per centimetre or foot, the calculation of the total number of lines generated by any circuit or coil, would merely be the product of the current, the length of the circuit, and a constant.

It should be remembered, however, that this deduction supposes theoretical conditions; that is, a filamentary wire having no appreciable diameter. How far the size of the wire introduces an error remains to be determined. At all events, if the diameter of the wire is small as compared with the diameter of the coil, and specially if the coil, as it usually does in practice, contains iron which appears to concentrate the lines in it, and therefore probably attracts those circulating in the body of the wire itself, it may doubtless be assumed that the ratio of the flux in two coils

would be equal to the ratio of their ampère-feet, which proportion might be of use in dynamo construction.

The above deductions were made by the writer a number of years ago, but as they did not appear to agree with some existing laws at that time, the matter was laid aside. It seems, however, that subsequently some dynamo builders have advocated and used this system of calculation in preference to the other, and it was therefore thought best to publish this proof, hoping that some others, well informed on this subject, might point out the discrepancies if any, and perhaps show the extent of the application in practice of calculating the magnetic flux of a current from the ampère-centimetres of the circuit.

THE PHYSIOLOGICAL EFFECTS OF ALTERNATING CURRENTS OF HIGH FREQUENCY.

BY PROF. EDWIN J. HOUSTON.

[*Read before the Electrical Section of the Franklin Institute, May 24, 1892.*]

GENTLEMEN:—I have concluded to place on record a brief statement of the substance of some remarks made by me at the last meeting of the section, concerning the physiological effects, on the human body, of alternating currents of very high frequencies.

As is well known, the physiological effects of alternating discharges of but moderate frequencies are more severe than are those of steady currents of the same current strength. As, however, the rapidity of alternation increases, the severity of the physiological effects decreases, until, at extraordinarily high frequencies, all harmful physiological effects practically disappear.

Three varieties of electric discharges or currents are employed in electrotherapy for the treatment of diseased conditions of the body.

(1) The steady, continuous currents produced by voltaic batteries, and called, in electrotherapeutics, Galvanic currents.

(2) The alternating currents produced by induction coils and called, in electrotherapeutics, Faradic currents.

(3) The electrostatic discharges obtained from frictional or influence machines and called, in electrotherapeutics, Franklinic currents.

As is well known, the physiological effects produced by Galvanic currents differ markedly from those produced by Faradic currents. The former, unless very powerful, produce on the opening or closing of the circuit, a contraction that is of very short duration—in fact almost but momentary; the latter produce a contraction that continues as long as the current is passing. This is generally believed to be due to the fact, that the contractions attending the opening and closing of the circuit, follow one another so rapidly that the muscles fail to assume the condition of rest and so present the appearance of continuous contraction.

Franklinic currents produce, in general, effects somewhat similar to those of Faradic currents.

When alternating currents are sent through the human body the physiological effects increase in severity with an increase in the current strength. With current strengths greatly in excess of those employed in electrotherapy additional effects are produced, and a tonic contraction of the muscles follow. Moreover, in such cases the severity of the physiological effects is increased by the high potential of the break-induced discharge.

As, however, the rapidity of alternation increases, the severity of the physiological effects decreases until, when enormously high frequencies are reached, the discharges become harmless. These facts have been demonstrated by Dr. Tatum for comparatively high frequencies, and by Nikola Tesla for enormously high frequencies.

In a lecture delivered before the American Institute of Electrical Engineers, at Columbia College, New York, on May 20, 1891, Tesla, speaking of these effects, says:

"I have found that by using the ordinary low frequencies, the physiological effects of the current required to maintain, at a certain degree of brightness, a tube four feet long, provided at the ends with outside and inside condenser

coatings, is so powerful that I think it might produce serious injury to those not accustomed to such shocks; whereas, with 20,000 alternations per second, the tube may be maintained at the same degree of brightness without any effect being felt.

"This is due principally to the fact that a much smaller potential is required to produce the same light effect and also to the higher efficiency in the light production. It is evident that the efficiency in such cases is the greater the higher the frequency, for the quicker the process of charging and discharging the molecules, the less energy will be lost in the form of dark radiation."

The severity of the physiological effects attending any electric discharge through the body must necessarily depend to a considerable extent not only on the quantity of energy present in the discharge, but also on the time in which it is acting.

It has occurred to me that in another circumstance is to be found, perhaps, the principal cause why discharges of enormously high frequency of alternation should be so comparatively harmless. This fact, I think, is to be found in the manner in which, according to our modern ideas, an electric discharge is believed to pass through a conducting path or circuit, viz: that the electric energy is not propagated through the mass of the conductor itself, but rather through the dielectric or other medium lying outside the conductor. That the electric energy is rained down on the surface of the conductor from the space outside it, and sinks down into the mass of the conductor, the conductor forming a sink or place where the energy can be dissipated.

In the case of a steady, continuous current, the energy sinks or soaks rapidly through the mass of the conductor, so that the electric current, in the language of the old ideas, passes through all portions of the mass of the conductor.

In the case of alternating currents, however, the energy received from a single impulse or electrical movement, by sinking or soaking moves (say) from the surface of the conductor towards the centre, only while such impulse con-

tinues; and, when the direction of the impulse changes, moves in the opposite direction, or towards the surface. In conductors through which alternating currents are passing, the current density is therefore greatest near the surface portions, and, in the case of alternations of very high frequency, the central portions of the conductor are entirely free from electric currents, the current being limited to portions near the surface.

In the case of the enormously high frequencies employed by Tesla, this action was so pronounced that conductors failed completely to conduct.

When, therefore, the human body is subjected to the effects of discharges of alternating currents of enormously high frequencies, the superficial portions only are traversed by the discharges. The more deeply seated, vital organs, being thus free from current, such discharges are necessarily harmless.

As the frequency of alternation increases, the body becomes more and more protected, until, when the frequency becomes as great as that of the ether waves, which cause sunlight, they would probably produce on the surface of the body the same genial effects as are produced by the light and heat of the sun, with which they are probably identical.

If these views are correct, it would appear that when the human body is exposed to rapidly-alternating discharges, it is subjected at one moment to a discharge that might produce instant death, were it not for the fact that the bolt is practically no sooner hurled at the body than it is hurled away from it.

A GRAPHIC REPRESENTATION OF THE MAGNETIC FIELD.

BY PROF. EDWIN J. HOUSTON.

[*Read before the Electrical Section of the Franklin Institute, May 31, 1892.*]

Being engaged in a study of the magnetic field and desiring to obtain some simple method of fixing and readily reproducing the peculiarities of different fields, I have, after numerous trials, succeeded in devising a modification of an old and well-known plan, so simple and efficient, that I have thought it may be of sufficient interest to others engaged in similar investigations, to describe it in detail.

The method consists essentially in forming a magnetic field with iron filings on a plate of glass in the usual manner, and subsequently fixing the filings so as permit the plate to be used as a positive for obtaining a blue print, a silver print, a platinotype, or any other photographic print.

In order to readily fix the groupings of filings on the glass plate while in the field of the magnet, a thin film of wax is spread over one surface of the plate by any suitable process.

A convenient method of waxing the surface of the plate consists in first gradually heating the plate until its temperature is above that of the melting point of wax, and spreading melted wax over its surface by means of a brush. The surplus wax is then allowed to drain off the plate, or it may be wiped off by a piece of warmed paper. The remaining wax is then spread in an even film over the surface by cautiously heating the plate by a Bunsen flame or other suitable source of heat; or, the same thing can be effected by placing the plate in a vertical position in an oven or sand bath, supported on a suitable vessel so as to catch the surplus wax which drains off.

Plates can be readily covered in this manner with an uniformly thin coating of wax sufficiently transparent to permit them to be successfully employed for photographic

printing. For such purposes of course, only pure, white wax is employed.

The wax-covered glass plate so prepared is placed with its waxed surface upwards, in a horizontal position over the

FIG. 1.—Field of bar magnets.

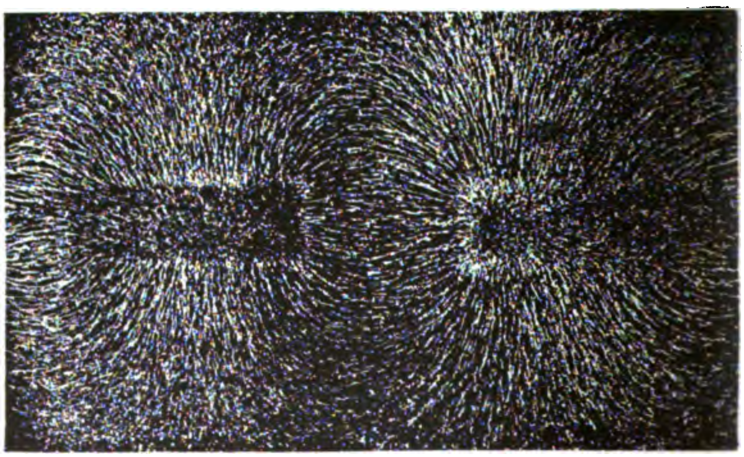


FIG. 2.—Opposite poles of bar magnets.

magnet whose field is to be fixed, and iron filings are sprinkled over its surface. The arrangement of the filings in the characteristic groupings of the field, is aided by gently tapping the plate in the usual manner.

When a satisfactory grouping of filings has been obtained, the field is fixed on the plate by gently warming it so as to melt the wax. At first I adopted the plan of carefully lifting the plate from the magnet and melting the wax by holding it over a source of heat, such as a Bunsen burner; but, no matter how carefully the plate was lifted from the magnet, or how nearly it was raised vertically from the same, so as to avoid lateral displacement of the filings, a change of figure almost invariably attended its removal. Better results were obtained when the wax was melted while the plate was in place over the magnet. This can readily be

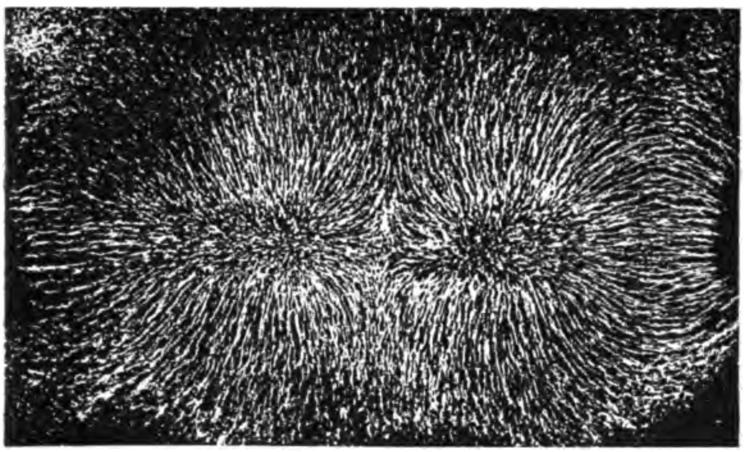


FIG. 3.—Similar poles of bar magnets.

effected either by holding a heated plate over the warm surface, or more conveniently by cautiously heating it by a Bunsen flame. After a slight heating, the flame may be permitted to play directly on the surface of the filings without displacing them.

After cooling, the plate with its fixed groupings of iron filings may be used as a positive for photographic printing. For this purpose it is placed in a printing frame with its surface of wax-fastened groupings of filings upwards, so as to come into contact with the surface of the sensitized paper.

If the plate has been properly prepared, but comparatively few filings will become detached from the waxed sur-

face when it is brought into contact with the sensitized paper. These should be blown off before taking a second print from the plate.

In order to obtain the minimum of roughness of surface,

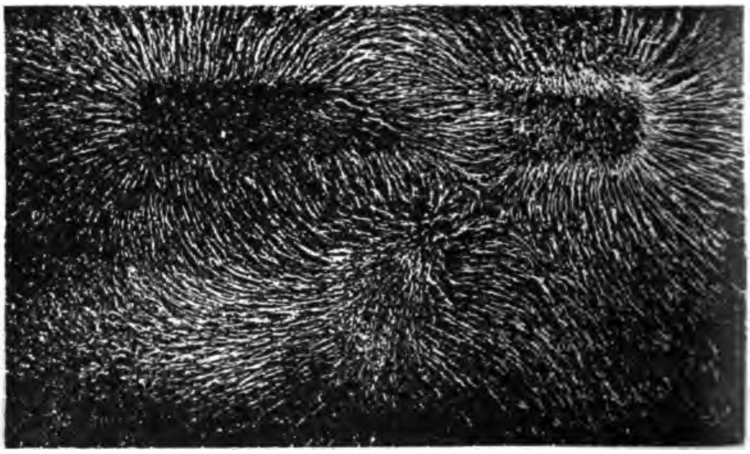


FIG. 4.—Bar magnets at right angles to each other.

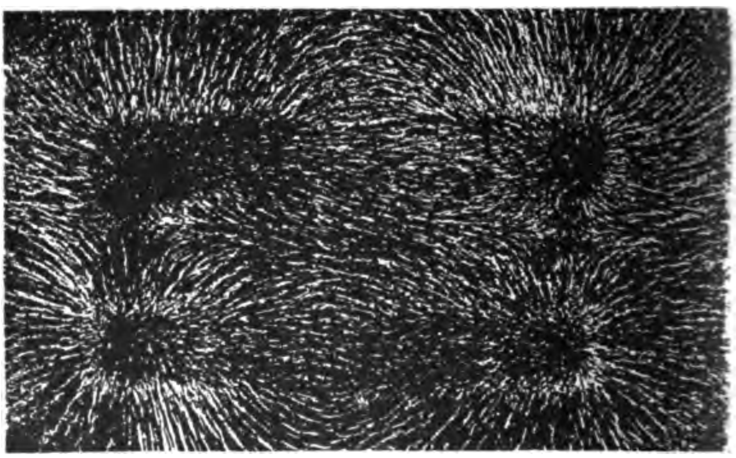


FIG. 5.—Parallel bar magnet. Similar poles opposed.

it is necessary to use filings that are as nearly as possible of a uniform size. This can be readily ensured by previously sieving them through a fine meshed wire gauze.

It is advisable that the plates be covered with as smooth a coating of wax as possible. Otherwise, the filings will be

prevented from readily arranging themselves in the directions which the lines of magnetic force pass.

In the case of powerful electro-magnets care must be taken to avoid a too great motion of the filings to the poles, since, in this manner, the portions of the surface over which the particles are moved, are swept clean of filings.

The best results are obtained by sieving the filings over the plate through a sieve whose meshes are sufficiently fine to ensure a small quantity only of filings falling on the plate at any one time. This, of course, is necessary to ensure the uniform distribution of the filings in the field of the magnet.

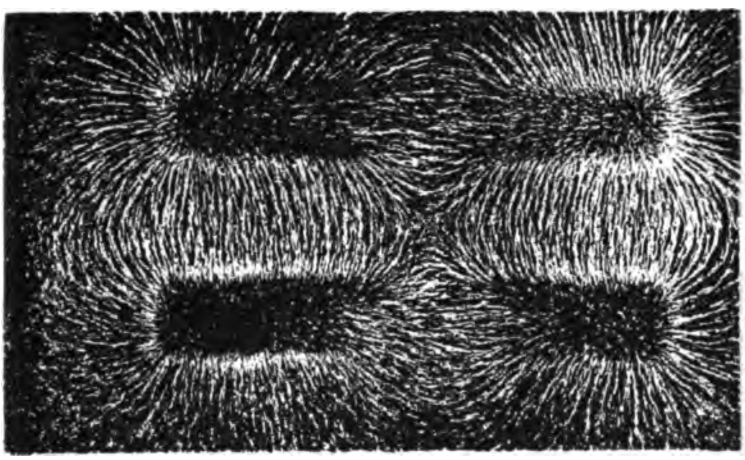


FIG. 6.—Bar magnets. Dissimilar poles opposed.

When the plates on which the magnetic fields are so fixed, are used for positives for photographic reproduction, and negative prints obtained therefrom in black, as by means of a silver print, or a platinotype, such prints can readily be used for the purposes of graphic reproduction for printing by any of the well-known photographic processes. In this way cuts and illustrations of actual fields can be readily had for purposes of illustration, without the introduction of those well-known errors arising from the too great artistic imagination of the copyist.

For purposes of subsequent reproduction I find platino-

type paper the best, as it gives dead blacks, that contrasting markedly with the white lines and spaces occupied by the iron fillings are readily photographed by any of the well-known processes of reproduction.

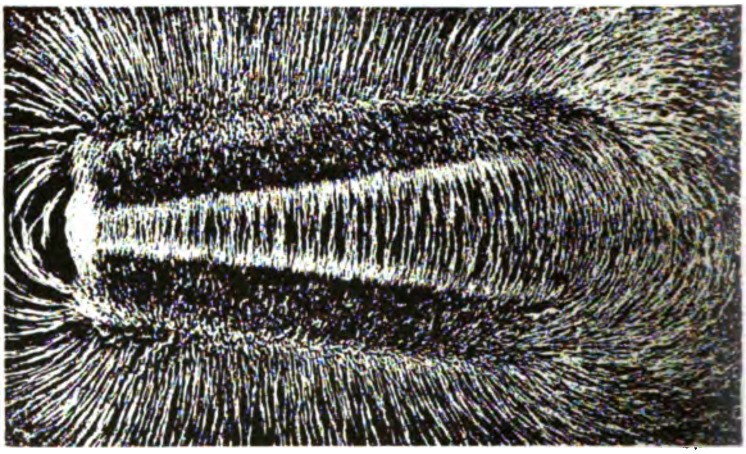


FIG. 7.—Field of horseshoe magnet.

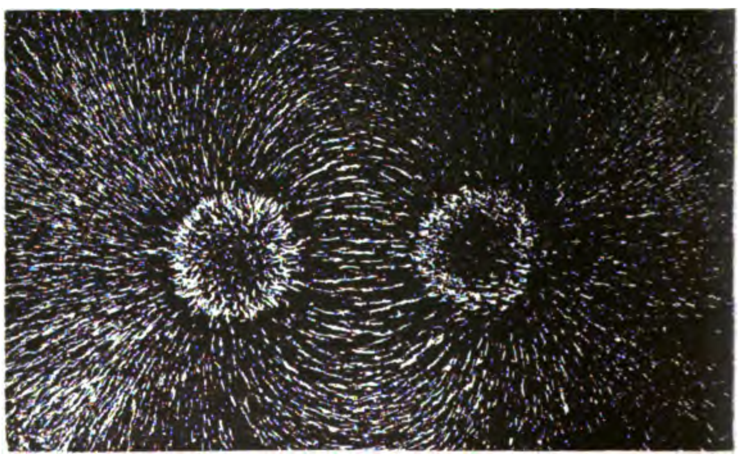


FIG. 8.—Field of electro-magnet.

When the filings are dusted over the plate from a sieve held a few feet above the waxed surface rather than quite near its surface, a better grouping of the filings is obtained.

I have prepared a number of fields according to the pro-

cesses described. They have been printed by the platinotype process.

In *Fig. 1*, is shown the field of a straight bar magnet. The characteristic radiation of the lines of force at the poles is well shown, as well as the curved lines produced by the mutual attraction of the lines coming out of the north and proceeding towards the south pole. The numerous parallel lines at the equator of the magnet show the strength of the magnetic flux at that point.

Fig. 2, shows the field produced by the approached, unlike poles of two straight bar magnets. The attraction of the

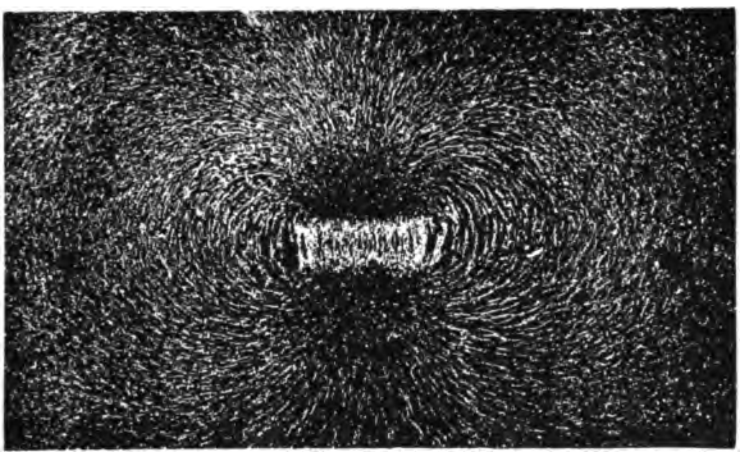


FIG. 9.—Field of permanent horseshoe magnet.

oppositely directed lines of force in the space between the opposing poles, as well as the increase in the length of space on the bars from which the lines pass off approximately at right angles to the surface, are well marked.

Fig. 3, shows the field produced by the approached, similar poles of the same straight bar magnets used in *Fig. 2*. The repulsion of the similarly directed lines of force producing nearly straight paths in lines at right angles to the length of the magnet, as well as a curious space midway between the poles, bounded by apparently hyperbolic curves are clearly seen.

Fig. 4, shows a very curious field produced by two bar magnets placed with their axes at right angles to each other so that one of the poles of one magnet is placed at right angles to the neutral point of the other and at a short distance from it. At the left-hand of the field is shown the curved deflections of the lines of force produced by the attractions of opposite poles. The lines of force coming out of a north pole and those entering at a south pole mutually attract one another and produce curves similar to those shown in the space between the approached, opposite poles shown in *Fig. 2*. At the right-hand of the field the repul-

FIG. 10.—Wire field of bar magnet.

sions existing between the similarly directed lines of force produce characteristic parallel streamings. The curious area bounded by hyperbolic curves is shown in the space between the poles at the right of the figure.

Fig. 5, shows the field produced by two straight bar magnets placed with their axes parallel to each other and their similar poles near together. The mutual repulsions of their fields are clearly shown. The curious areas bounded by hyperbolic curves are shown in the spaces at each end between the poles of the magnets.

Fig. 6, shows the field produced by the same parallel bar magnets placed with their opposite poles near together.

The attraction of their oppositely directed lines of force is well marked. In the neighborhood of their neutral points, a very marked area bounded by hyperbolic curves is seen. The strength of the magnetic flux near the neutral points is also marked.

Fig. 7, shows the field of an ordinary horseshoe magnet. The magnetic leakage between the sides of the bar is marked, as is also the strength of the magnetic flux in the neighborhood of the equator or neutral point of the magnet.

Fig. 8, shows the field of an electro-magnet. In order to

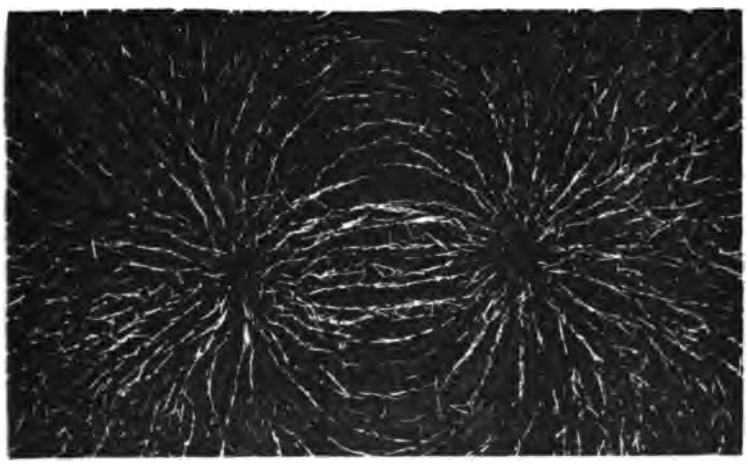


FIG. 11.—Wire field of electro-magnet.

avoid the injurious sweeping action of the particles as they are carried bodily forward towards the poles, I found it necessary to use a very weak current, and to place the plate a short distance above the poles.

It may be mentioned in this connection that it is in general advisable to avoid resting the plate on the surface of the magnet, since when the plate does not touch the poles it is left free to be gently tapped or vibrated so as to permit the filings to arrange or group themselves while in the field of magnet.

Fig. 9, shows the field of a peculiarly shaped permanent

horseshoe magnet taken in a plane over the poles at right angles to the length of the magnet. I was rather surprised in this case to find that so many of the lines of force passed through extended air circuits shown rather than through the narrow gap directly between the poles.

Fig. 10, shows a novel field obtained by short lengths of very thin iron wire, that act as small magnetic needles. The field is that of the bar magnet employed in *Fig. 1*. Although the separate particles do not possess as great freedom of motion as the shorter and smaller iron filings, yet their tendency to come to rest with the lines of magnetic

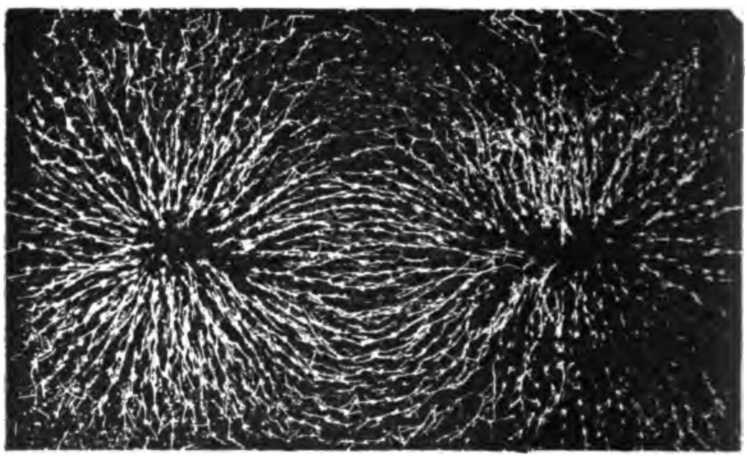


FIG. 12.—Wire and filings field.

force passing through their greatest dimensions, so as to reduce the resistance of the magnetic circuit as much as possible, is manifest.

The peculiar wire field produced by these means is of especial interest when studied in the light of Ewing's theory of magnetism.

Fig. 11, shows another wire field produced by the same electro-magnet as is employed in *Fig. 8*. The polarization of the minute magnetic needles and their arrangement in groupings of polarized chains is well marked.

Fig. 12, shows a field produced by iron filings and iron

wire. The peculiar groupings of the iron wire in chains of polarized particles are clearly shown.

A curious resemblance is possessed by this field and other wire fields to the discharge produced by a lightning flash, or other high potential discharge; such, for example, as the recent 500,000 volt discharge of Elihu Thomson. This resemblance quite naturally leads to the speculation, whether the peculiar forked or curved shapes of such discharges are not due to similar causes, viz: to polarized chains of particles of the medium which offers paths of less resistance to the discharge than the spaces adjoining or surrounding them.

I am making some experiments in solid fields, *i. e.*, in the peculiarities of the distribution of the lines of force in the space of three dimensions surrounding magnets, which I trust to be able shortly to bring before you.

I desire to express my indebtedness to my assistant, Mr. B. F. Lacy, for valuable aid in preparing the plates.

Since writing the above my attention has been called to the fact that the process above described has been very fully anticipated by Prof. Mayer, in a publication printed in the *Journal of the Franklin Institute*, for May, 1871. As my process differs in some particulars from that described by Prof. Mayer, and as it appears to me advisable to call attention to both processes at this time, I have concluded to permit the paper to go to publication. To Prof. Mayer, however, the credit is due for the first conception of the general process.

Since writing the above on last Saturday, I have devised a new plan which I believe to be far in advance of what I have just described.

According to this plan I place a dry sensitized photographic plate over the magnet whose field I desire to fix and after the characteristic groupings of filings have been obtained, I expose such plate while over the magnet to the light of a gas flame for a few seconds.

This operation is necessarily performed in the dark photographic room. After exposure the light is turned out and only the non-actinic red or yellow light left. The filings are allowed to fall off the surface of the dry plate, and the

finer particles that still adhere to it are brushed off by a feather or dry camel's hair brush. The plate is then developed and fixed in the usual manner.

The removal of the adherent iron dust by the feather or brush is preferable to the use of the breath, as this is apt to produce troublesome spots.

I have found that the so-called lightning gelatine dry plates give very satisfactory results when employed for such purposes.

This process of obtaining records of magnetic fields produces true negatives, which when employed for printing by blue print, silver print, platinotype, or similar process produce excellent positives.

As the negatives so obtained are more permanent than the positives obtained by the use of the filings themselves, they permit the taking of an indefinite number of photographic prints.

I have thought of forming the field directly on the surface of sensitized paper and exposing such to light. But such paper is apt to curl, and such processes produce but a single impression.

The time has been too short to prepare many specimens of fields by this new process. I hope to be able, however, by the next meeting of the section, to present such results in a short paper.

SOME ADDITIONAL NOTES ON THE GRAPHIC REPRESENTATION OF MAGNETIC FIELDS.

BY PROF. EDWIN J. HOUSTON.

[*Addendum to a paper read before the Electrical Section of the Franklin Institute, June 28, 1892.*]

In a paper read at the last meeting of the Section, entitled "A Graphic Representation of the Magnetic Field," I described a process for readily fixing and reproducing the peculiarities of different magnetic fields, which consists essentially in forming the fields on wax-covered plates, subsequently fixing the same by gently warming the wax, and employing the plate so prepared as a positive from which photographic prints can be readily obtained.

I also briefly described in the same paper a different process for the ready reproduction of such fields, in which the collections of filings are formed in the dark photographic room, directly on the sensitized surface of a plate, which is afterwards exposed for a few seconds to actinic light and subsequently developed, and promised a further description of this method at this meeting.

It will readily be seen that this process differs from the other, in that it produces photographic negatives, in place of the positives formed by the former process.

Since the last meeting of the Section, I have experimented some little on the new process, and have obtained very satisfactory results.

For the convenience of those who have neither read the former paper, nor attended the meeting of the Section at which it was read, I will describe the process in full, together with the details which are necessary in order to ensure the best results.

All actinic light being excluded from the dark room, and the red light being turned down as far as will permit the plate to be seen, when the eyes have become accustomed to the dim light, a sensitized gelatine plate is placed with its sensitized surface upwards, on, or a short distance above, the magnet whose field is to be obtained. Iron filings or bits of wire are then carefully dusted over the sensitized surface, and obtained thereon, in characteristic groupings, by gently tapping the plate with a pencil or similar object in the usual manner.

The plate is then exposed to the light of a gas jet for a length of time that will of course depend on the nature of the plate, its sensitometer number, and the character of the effect it is desired to obtain.

When very rapid plates are used, the shortest time during which a gas burner can be turned on and off is sufficient. I have, however, obtained the best results from the light of an ordinary friction match held above the plate and at a distance from it of about twelve feet. The match is lighted and immediately blown out. Even this short exposure appears to be greater than is required. With fairly slow plates I have found that an exposure of about three seconds, with a two-candle gas jet, at a distance of about four feet from the plate, gives excellent results.

The plate is then turned on edge so as to allow the filings to fall off its surface, and any dust that remains is carefully removed by a camel's-hair brush, and the plate is developed in the ordinary manner.

Since it is desired to obtain sharp contrasts of black and white, the best results are obtained by the use of bromides in the developer for the purpose of retarding the rapidity of development. After developing, the plate is treated for a few moments to an alum bath, and is then fixed in the hypo bath as usual.

Should the depth of the negative thus obtained be insufficient, the plate may be subjected to the action of a suitable intensifier. I have found a silver intensifier to give good results.

The specimens which I exhibit to-night were obtained either from Carbutt's or from Seed's gelatine plates.

In some of these experiments, Carbutt's plates, sensitometer No. 16, were exposed for about three seconds to the light of an ordinary gas burner, turned down to about two candles, and situated about five feet from the plate. From some experiments in this direction I am inclined to believe that the time of exposure under these circumstances can advantageously be decreased.

I employed for these plates the following developer:

NO. 1.

Water,	16	ounces.
Sulphite of soda,	307	grains.
Para-amido-phenol,	$76\frac{3}{10}$	"

NO. 2.

Water,	16	ounces.
Sulphite of soda,	307	grains.
Caustic soda,	230	"

Equal parts of Nos. 1 and 2 are mixed for use. For time exposure the above mixture is diluted with from two to four parts of water.

Any good developer, however, will answer.

I have also used Seed's plates, sensitometer No. 23. With these plates the momentary turning on and off of the gas jet gives a sufficiently long exposure.

I have also obtained very good results with Seed's plates sensitometer No. 26-x. With these plates my friend, F. Gutekunst, of Philadelphia, has prepared some excellent fields.

In order to protect the plates from the light of the gas jet while lighting it, so as to avoid too long an exposure, the expedient was adopted of covering the plate with a developing dish until the light was turned on. It was then exposed while the dish was being rapidly removed from the plate

the gas being turned off when the dish was about one and one-half feet distant from the plate.

While myself out of the city and, therefore, away from my laboratory, my friend, Mr. F. R. Lefferts, of the Celluloid Company, of New York, kindly placed a photographic dark room at his cottage, at Belmar, N. J., at my disposal during these experiments. I am also indebted to him for valuable aid in preparing the photographic plates.

Fig. 1 shows the wire field of a straight bar magnet of steel. This corresponds to the bar magnet, the field of which was shown in the first paper on *Fig. 10*. This, like the other wire fields, was obtained by the use of short lengths of soft iron wire instead of iron filings.

Fig. 2 shows the filings field of a simple horseshoe magnet. The anomalous poles in this magnet show very peculiar groupings in the neighborhood of what was originally the neutral point of the magnet. These poles were probably caused by some unauthorized juvenile experiments I had not counted on being made.

Fig. 3 shows the field of two parallel straight bar magnets with their similar poles approached. This figure corresponds to *Fig. 5* of the first paper.

Fig. 4 shows the field of two parallel straight bar magnets with their dissimilar poles approached. This figure corresponds with *Fig. 6* of the first paper. The conditions for the exposure of this field were more favorable than for most of the others, and the print shows what can be hoped for when the proper conditions necessary to ensure the best results are exactly understood.

Mr. Lefferts has kindly prepared for me an excellent transparency of this field, which I now show you.

Fig. 5 shows the field produced by two straight bar magnets placed with their axes at right angles to each other, and with their similar poles approached. The characteristic parallel streamings, produced by the repulsion of similar lines of magnetized particles, are clearly shown.

Fig. 6 shows the field produced by the straight bar magnets with their axes at right angles to each other and with their dissimilar poles approached.

Fig. 7 shows the field of the two straight bar magnets placed with their axes at right angles to each other, and the pole of one near, but not in contact with, the neutral point of the other. This corresponds to *Fig. 4* of the first paper.

Fig. 8 shows the filings field of a compound permanent horseshoe magnet. This figure corresponds with *Fig. 7* of the first paper.

Fig. 9 shows a curious field of the same permanent horseshoe magnet shown in the former paper in *Fig. 9*. In this figure, however, the magnet is placed with its axis in a horizontal position, while in the figure of the first paper it was placed in a vertical position. I have reproduced *Fig. 9* of former paper in *Fig. 10* for ready comparison. The leakage, in planes at right angles, is well shown The magnetic leakage in this case gives the curious appearance of a "beatified bottle."

I also show you a number of aristotypes prepared for me by Mr. Lefferts.

I have formed some curious compound fields with filings and wire mixed. *Figs. 11* and *12* show such fields corresponding to *Figs. 3* and *4*, as shown above.

PROCEEDINGS.

[*Stated meeting, held Tuesday, June 28, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 28, 1892.

Prof. Edwin J. Houston, President, in the chair.

Present, twenty-one members and visitors.

The minutes of the previous meeting were read and approved.

The Treasurer reported the cash balance in the treasury, and presented bills for printing and lantern slides, which were approved and ordered paid.

Mr. D. A. Partridge exhibited and described a Thomson reflecting electrometer that he had constructed from drawings illustrating a paper on the subject by Sir Wm. Thomson. The instrument was beautifully made, and showed remarkable sensitiveness.

Mr. Paul Winand read the second part of his paper on "Some Points Regarding Multiphase Current." Referred for publication.

Prof. Edwin J. Houston gave "Some Additional Notes on the Graphic Representation of Magnetic Fields." Referred for publication.

Mr. Richard W. Gilpin described a curious changing of polarity met with in a four-pole compound dynamo.

The meeting then adjourned.

L. F. RONDINELLA, *Secretary.*

ON POLYPHASED CURRENTS.

BY PAUL A. N. WINAND.

[*A paper before the Electrical Section, at the stated meetings of April and May.*]

Since last year's electrical exhibition at Frankfort, the transmission or distribution of energy by means of polyphased currents, seems to have attracted, to a remarkable degree, the attention of all interested in electrical matters. This system had been proposed and experimented upon for several years previously, but it is only since the successful outcome of the Lauffen transmission that its practical advantages have been generally recognized.

Little has been published as yet in this country concerning its theoretical features, while a number of papers on the subject have appeared in Germany. As the German papers mostly treat the matter in a purely mathematical manner, which is not always favorable to clear insight into the somewhat intricate conditions, I have endeavored to apply to the question a more direct way of reasoning. I fear, however, that I have succeeded but imperfectly in my purpose.

GENERAL CONSIDERATIONS.

The term polyphased or multiphased currents has apparently not yet received a strict definition. It is broad enough to cover any system or combination of connected conductors carrying each an alternating current different in phase from the currents carried by the other conductors. In fact, however, it seems to have been used for designating such systems of alternating currents

> which *can be producea* by means of an armature without commutator, uniformly rotating relatively to a constant field and opposing to the motion a orque which is a constant during the whole of a revolution, or which, by means of stationary and

> permanently connected conductors, ***can generate*** an uniformly rotating, constant field.

The field, in this second case may or may not be provided with iron cores of suitable shape.

The currents and electro-motive forces are generally supposed to follow the simple *sine* law, as usual.

It is possibly by looking at it in this way that the chief promoter of polyphased currents in Germany, Mr. M. von Dolivo-Dobrowolsky, has been led to propose the name of "Drehstrom," or rotary current.

It is evident that in a system of polyphased currents which conforms to the above conditions of possible origin or possible effect, the individual currents and electromotive forces are not arbitrary, but inter-related as to amplitudes and phases.

One general and characteristic property of a system of currents conforming to this definition can be proved before going into further details.

> The rate at which the total energy is generated, transmitted or absorbed in the system is the same at any moment of a period.

This follows directly from the assumption that the torque and the speed are uniform, which means that the rate of consumption of mechanical energy is constant during a period, while the efficiency of conversion is supposed, as usual to be constant during that time and because no energy is momentarily stored up in the armature.* The energy delivered at the terminals is then constant, and it will be so also through the whole system if there is no momentary storing up of energy by reason of capacity effects. Such effects may even be present without disturbing the conditions if properly distributed.

The second alternative of the definition (consisting in simply generating a field) is really equivalent to the first for the case that the torque is $= O$.

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* See the paper published since by Mr. C. Steinmetz, in *Electrical World*, of July 16, 1892.

Any system of polyphased currents, however irregularly the phases may be distributed in time and however different the currents may be in magnitude, will thus be governed by this condition of uniform rate of energy together with the general laws of circuits. That the sum of the currents in all conductors of the system which any continuous infinite surface may cut is at any moment $= O$; and that the difference of potential between any two points on the conductors is at any moment equal to the sum of the electro-motive forces* along any path which may be followed along the conductors to lead from one point to the other.†

We will not dwell any longer on the question taken in its most general form, because in practical applications

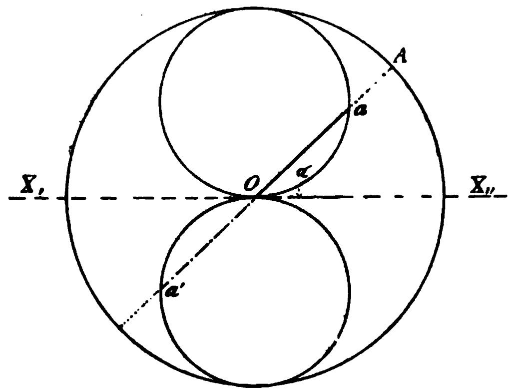

FIG. 1.

polyphased currents are (or, at least, are intended to be) symmetrical; that is, the phases are evenly distributed over the time of one period and the currents are of the same intensity.

SYMMETRICAL SYSTEMS.

The current and electro-motive force in each conductor

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* These electro-motive forces include $e = i\ R$ taken with the sign of i.

† This is practically equivalent to the law stated by Helmholtz in 1853: That, if in any system of conductors there are electro-motive forces in different parts, the electric tension in any point is equal to the algebraic sum of the tensions which each individual electro-motive force would produce when acting independently of all the others.

are of necessity alternating since there is no periodical commutation of connections. They can be represented as usual by drawing a *sine* curve, and the relations between several of them can be shown by putting the curves along the same axis, but shifted by amounts corresponding to the relative phases.

It is sometimes more convenient to use, as suggested by Prof. Silv. Thompson, the geometrical property which is well known to mechanical engineers by its application in Zeuner's slide-valve diagram.

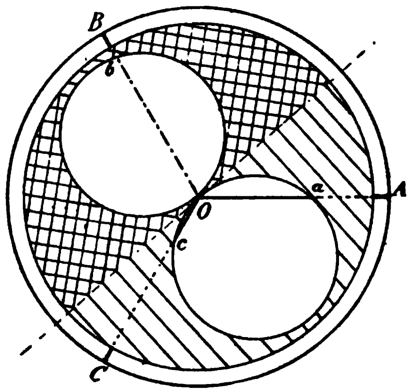

FIG. 2.

Fig. 1 represents this method, which we shall apply later on.

The length Oa, cut off by the small circle on the radius $O\ A$, is proportional to *sin a*, being the angle of $O\ A$ with the diameter $X_1\ O\ X_{11}$. When the radius is below $X_1\ O\ X_{11}$ *sin a* is negative and this is shown by the part cut off being in the lower circle, like Oa'.

The different length cut off on several radii drawn at angles corresponding to the phases will thus show at a glance the simultaneous values of currents or of electro motive forces in a corresponding polyphased system. If a model be made in which the radii can be rotated together, relatively to the circles, the succession of simultaneous values will appear in a striking manner. It has proved convenient to draw the radii on one sheet and to extend

them to a larger circle, while another sheet, out of which the small circles have been cut, is rotated on top of the first. The two halves of this sheet are made of different appearance, so as to show at once which quantities are positive and which are negative. *Fig. 2* shows this disposition for a three-phase system.

Polyphased generators can be built almost entirely like alternators, and, as for these, it is often convenient to have the armature stationary and the field rotating. Let us con-

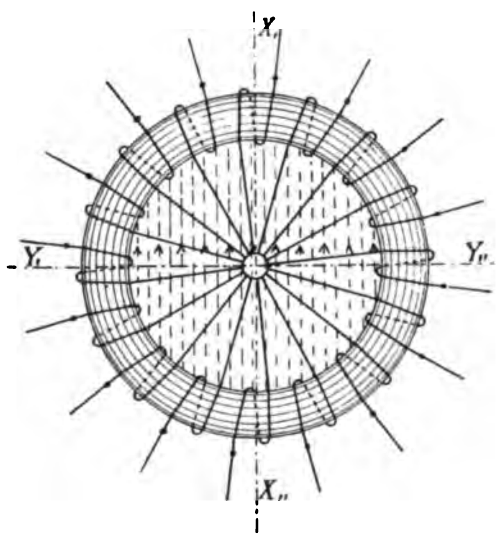

FIG. 3.

sider more closely the simple case of a ring armature with rotating bipolar internal field.

The successive coils of the armature may be connected in two simple ways:

All their right-hand ends may be connected together and their left-hand ones to the terminals of the machine, hence each to one wire of the line, as shown in *Fig. 3*. This has been called the *star* combination. Or the coils may be connected in one series, like a Gramme ring, and the points of junction connected to the terminals (*Fig. 4*), which has been called the *mesh* combination.

We may now trace the distribution of differences of potential and currents at any moment in the conductors.

X_1 X_{11} is the direction of magnetic axis, Y_1 Y_{11} a perpendicular to it. Taking each coil separately, the electromotive force e, generated in it is maximum for the coils at X_1 X_{11} and $= O$ for those at Y_1 Y_{11}, and so are the currents also, if there be no lag, which we will assume for the present.

In the *star* combination the difference of potential E_{1s} between two diametrical terminals is equal to twice the

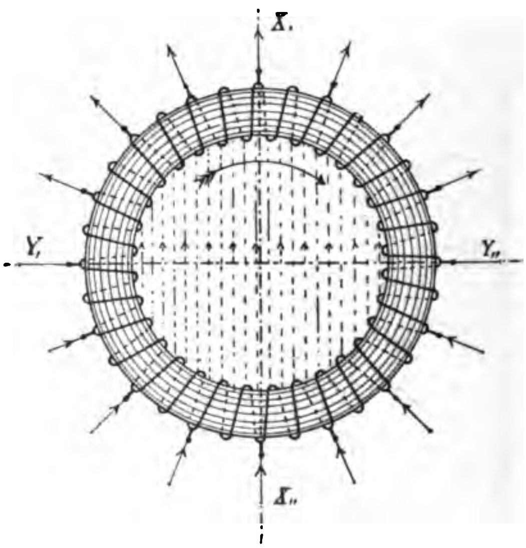

FIG. 4.

electro-motive force e of the opposite coils connected to those terminals, it is

$$E_{1s\,max} = 2e_{max}$$

for the terminals at X_1 X_{11}.

The difference of potential between adjacent terminals is

$$E_{11s} = e_x - e_{x+1}$$

It is equal the difference of the electro-motive forces in the two corresponding coils.

Necessarily

$$E_1 = \Sigma E_{11}$$

for half the ring in both the *star* and the *mesh*.

In the *mesh*, however,

$$E_{\mathrm{IIm}} = e$$

so that

$$E_{\mathrm{Im}} = \Sigma e$$

It is interesting to compare the cases where everything is the same (including amount and size of wire), the only difference being in the number of coils (or phases) and in their combination as star or mesh. It is easy to see that in mesh E_{Im} is due to the induction on all the turns of one-half of the ring. The difference of potential between

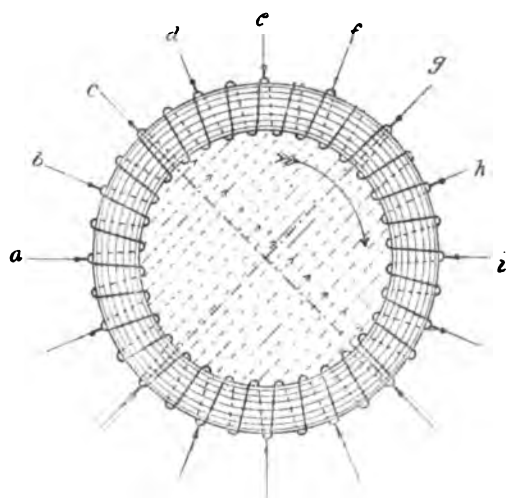

FIG. 5.

opposite terminals is thus independent of the number of coils, but the difference of potential between adjacent terminals, taken at same distance from Y_{I} Y_{II} is inversely proportional to the number of coils because it is proportional to the number of turns per coil.

In star, since $E_{\mathrm{Is}} = 2\,e$ the difference of potential between opposite terminals is inversely proportional to the number of coils, but the difference of potential E_{IIs} between adjacent terminals is, at the same distance from X_{I} X_{II}, nearly inversely proportional to the square of the number of coils.

This is due to the fact that this difference E_{11s} is not only proportional to the number of turns per coil, but also to the distance between the centres of said coils along the ring.

The field N S may have any more or less regular shape or distribution and accordingly the electro-motive force in a coil will vary in different ways, as the case may be, with the angular displacement α or with time, as we suppose the motion uniform. For the star the law followed by the difference of potential between opposite terminals is the same as that followed by the electro-motive force in a coil.

For the mesh the law will generally be a different one. As shown above, the difference of potential is, in this case, equal the sum of the electro-motive forces induced in all the coils on one-half of the ring. The difference of potential, between a and i, for instance (*Fig 5*) can therefore, at any time, be considered as equal to electro-motive force in winding from a to h, *plus* electro-motive force induced in coil h i.

$$a\,i_1 = a\,h + h\,i$$

After the field has moved through an angle equal to the distance of two consecutive coils, the same portion of the field to which was acting on the portion a h of the winding. is now acting on the equivalent portion b i and the difference of potential at this moment is

$$a\,i_{11} = b\,i + a\,b$$

The variation,

$$\Delta\,a\,i = a\,i_1 - a\,i_{11}$$

of the difference of potential between the opposite terminals a and i after this angular displacement equal to the space of one coil is thus

$$\Delta\,a\,i = a\,h + h\,i - (b\,i + a\,b)$$

but it is evident that

$$a\,h = b\,i$$

and when the number of coils is large;

$$h\,i = -\,a\,b,$$

because then coils a b and h i are practically opposite, if we

only assume that the field, where it meets the armature, is symmetrical around the centre of rotation.

Consequently

$$\Delta a\, i = 2\, h\, i$$

or

$$= 2\, a\, b$$

$$= 2\, e$$

This means that the *variation* of the *difference of potential* between opposite terminals in the *mesh* is equal to the *difference of potential* itself in the *star*, and that, for a large number of coils (or phases), if $E_{1m} = Fa$ is the law followed by the *difference of potential* in mesh, the law followed by the same quantity in star is the derivate function

$$E_{1s} = \frac{d\, Fa}{d\, a}$$

of the preceding.

Similar considerations would show that the reverse is true for the difference of potential between adjacent terminals.

$$E_{11s} = Fa$$

and

$$E_{11m} = \frac{d\, Fa}{d\, a}$$

hence

$$E_{11s} = Fa$$

and

$$E_{1s} = \frac{d\, Fa}{d\, a}$$

and

$$F_{1m} = Fa$$

and

$$E_{11m} = \frac{d\, Fa}{d\, a}$$

There is only one form of the law for which

$$\frac{d\, Fa}{d\, a}$$

is equivalent to $F\, a$ itself; namely, when $F\, a$ is *sin a* or *cos a*,

which latter is the same as *sin* a, with one-fourth period difference of phase

$$\frac{d\,Fa}{d\,a} \text{ is then } + \cos a \text{ or } - \sin a,$$

and everything in the system, as well for the star as the mesh combination, follows the *sin* a law as long as the resistances, inductances and capacities can be considered as constants.

FIG. 6.

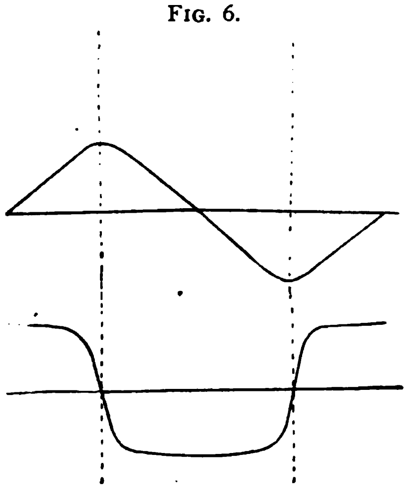

FIG. 7.

I will only remark further concerning this general case, that if $E = Fa$, when plotted gives curves of the kinds shown in *Fig. 6.*

$$E = \frac{d\,Fa}{d\,a}$$

gives curves like shown in *Fig. 7*.

It is generally desirable to have the currents and electro-motive forces follow the *sine* law and as this is sufficiently approximated in most practical cases, the subsequent considerations will be made under assumption of this law.

FIG. 6.

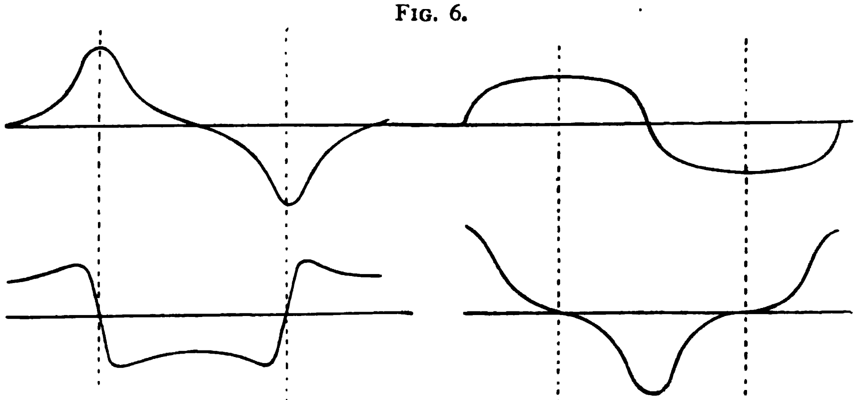

FIG. 7.

Returning then to *Fig. 3* and *Fig. 4* the rule that, for

mesh and star, the difference of potential of opposite and of adjacent conductors follow the laws.

$$Fx, \frac{d\,Fx}{d\,x}$$

and

$$\frac{d\,Fx}{d\,x}, \ Fx$$

which becomes in this case *sin* x, *cox* and *cos* x, — *sin* x, means that in *Fig. 4* the differences of potential are distributed along the terminals and occur in time in the same manner as in *Fig. 3*, excepting that everything is shifted by 90° relatively to the axis of the field.

The electro-motive forces generated in the individual coils are, however, in all respects, the same in both cases.

It means, besides [E_{1} being the difference of potential between opposite terminals and E_{11} between adjacent ones], that, as the values of E_{11} along the ring follow the *sine* law, and $E_{1\,max} = \Sigma\, E_{11}$ in both cases;

$$\Sigma_0^{\pi}\, E_{11} = E_{1\,max} = \frac{n}{\pi}\, E_{11\,max}$$

n being the total number of coils or terminals.

The same relation holds also for the mean differences of potential, or voltages V_{1} and V_{11}.

$$V_1 = \frac{n}{\pi}\, V_{11}$$

or

$$\frac{V_1}{V_{11}} = \frac{n}{\pi}$$

This is the relation of the voltages taken between opposite and adjacent terminals, and it is the same for the mesh and the star.

Continuing now the comparison between identical machines, the difference being only in the disposition as star or mesh, we find that the voltages compare as follows:

As the coils contain the same number t of turns in both cases

$$V_{1s} = 2\,a\,t$$

$$V_{1m} = \frac{n\,a\,t}{\pi}$$

a being the voltage per turn hence

$$\frac{V_{1m}}{V_{1s}} = \frac{n}{\pi}$$

in which, V_{1m} and V_{1s} are taken between opposite terminals.

The same relation is, from the preceding, also true for adjacent terminals.

If the armatures are wound so as to give the same voltages

$$V_{1m} = V_{1s},$$

but then the coils contain different numbers of turns t_m and t_s, and the same formulæ give

$$2\,a\,t_s = \frac{n\,a\,t_m}{\pi}$$

or

$$\frac{t_s}{t_m} = \frac{2\,\pi}{n}$$

Considering now the question of currents, we may first assume that they do not lag.

In the star combination they follow then the electromotive force generated in the coils and each line conductor carries the same current, A_s, as the armature winding.

In the mesh, the currents flow out of one-half of the armature into the line conductors and flow back into the other half, as shown in *Fig. 4*.

It appears that, as the current in armature conductors is maximum at $Y_{I}\ Y_{II}$ (this is the case in *Fig. 3* as well as *Fig. 4*) the current is maximum in the line conductors at $X_{I}\ X_{II}$; that is, at oo° from where it is maximum in the star combination.

The instantaneous value C_{I} of the current in armature is equal to the sum of the line currents C_{II} in the conductors

comprised between this point and point X. Consequently its maximum value is equal to the sum of line currents in quadrant $X\ Y$.

$$C_{\text{I max}} = \frac{n}{2\pi} C_{\text{II max}}$$

and if we call A_{Im} and A_{IIm} the mean values of currents in armature and line for the mesh:

$$A_{\text{Im}} = \frac{n}{2\pi} A_{\text{IIm}}$$

If we compare otherwise identical armatures, the cross sections $S_s\ S_m$ of wires are inversely as the numbers of turns per coil, and as we have found the latter to be

$$\frac{t_s}{t_m} = \frac{n}{2\pi}$$

in order to obtain equal voltage

we find $$\frac{S_s}{S_m} = \frac{2\pi}{n}$$

If we consider the machines as equally loaded when the currents are proportional to the cross-sections of conductors, then, for equal load,

$$\frac{A_s}{A_{\text{Im}}} = \frac{2\pi}{n}$$

This, with the previous equation

$$A_{\text{Im}} = \frac{n}{2\pi} A_{\text{IIm}}$$

shows that

$$A_s = A_{\text{IIm}}$$

which means that with otherwise identical machines, one having star the other mesh winding and such number of turns as to give the same voltage, the currents in line, and consequently the energy, will be the same if they are equally loaded.

Considerations almost entirely similar to the above would show that the relations found for the currents and electromotive forces in the armature and line conductors, apply

also to conductors considered as mere resistances, such as lamps.

We have assumed that there was no difference of phase between currents and electro-motive forces. There is generally such a difference, however, but, if everything is symmetrical, the relations between the currents and those between the electro-motive forces remain unchanged, the only difference with the case assumed before being that all what relates to the currents is shifted by an angle equal to the difference of phase relatively to the axis of the field.

It would be more complicated than difficult to show further in a similar manner, that, inversely, the same field can be produced by the same polyphased system with otherwise identical cores and windings, the only difference being in the arrangement as star or mesh.

We have considered more particularly the case of a ring armature. A drum might have been taken as well and would have led to similar results.

It may be interesting to note that the first idea of Mr. Haselwander, one of the pioneers in this line, had been to take two Thomson-Houston arc machines, having armatures of the drum type, and to use one as a dynamo, the other as a motor of a three-phase system. Contact rings would have been substituted to the commutators. He afterwards made use of ring armatures.

THREE-PHASE SYSTEM.

This system has, besides its simplicity, decided practical advantages of its own, These have apparently been first fully recognized and expounded by Mr. von Dolivo-Dobrowolsky, to whose efforts the successful introduction of this system in actual practice is mainly due. We may investigate the relations in this system by means of the diagram or model represented by *Fig. 2*. It shows the star and mesh combination, $O\,A$, $O\,B$, $O\,C$ being the branches of the star, while $A\,B$, $B\,C$ and $C\,A$ are those of the mesh. We have seen above that when the number of phases is large the phases in the star branches differ by nearly 90° from those in the corresponding parts of the mesh.

With as small a number of phases as three, the case is different. The use of the diagram *Fig. 2*, discloses the following facts:

In the moment corresponding to position *I* (*Fig. 8*), the current is maximum and positive in *O A*. Let C_s designate this maximum value.

In *O B* and *O C* the currents are both negative and of same value, by reason of symmetry. They are necessarily

$$= - \frac{C_s}{2}$$

In position *II* (*Fig. 9*), which corresponds to one-twelfth

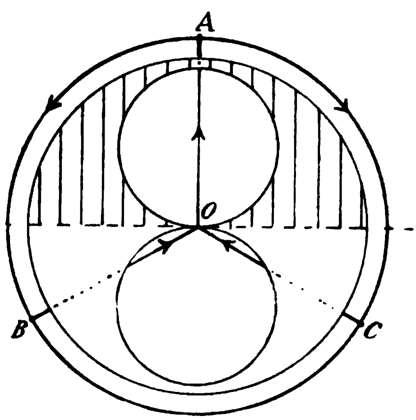

FIG. 8.

period later, or to a displacement of 30° the currents are equal and opposite in *O A* and *O B*.

Their numerical value is

$$\sin 60^\circ\, C_s = \frac{\sqrt{3}}{2}\, C_s = O,866\, C_s$$

At this moment there is no current in *O C*.

In position *III* (*Fig. 10*) [or after another one-twelfth period], the currents are

$$+ \frac{C_s}{2}$$

in both *O A* and *O C* and $- C_s$ in *O B*.

The phases and corresponding values of the currents in the branches of the mesh, can be ascertained as follows.

The currents in all conductors are alternating, and since we consider only the case where they follow the *sine* law, we conclude that in position *I*, by reason of symmetry, the current of $O\ A$, which is $= C_s$, divides itself into two equal parts flowing in opposite directions through $A\ B$ and $A\ C$,* so that it is

$$-\frac{C_s}{2}$$

in $A\ B$, and

$$+\frac{C_s}{2}$$

in $A\ C$, if we consider right-hand rotation as positive.

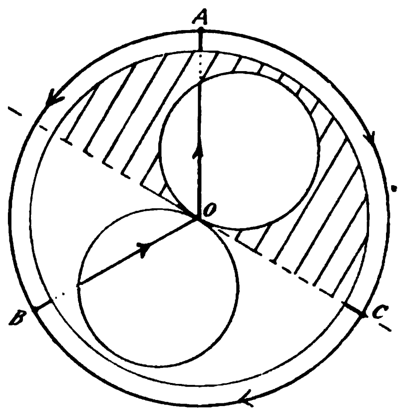

FIG. 9.

There is no current in $B\ C$ at this moment.

As the current in $B\ C$ follows the *sine* law, if it is $= O$ in position *I* it will be maximum one-quarter period or 90° later.

A comparison of *I* and *II* shows that the current is $= O$ in $O\ C$ one-twelfth period or 30° later than in $B\ C$. This means that the difference of phase between the currents in a branch of the mesh and in the adjacent branch of

* It would carry us too far to show that, to assume that the currents in $A\ B$ and $A\ C$ are not equal, is equivalent to assuming that there is a continuous current in the mesh conductors, and this would be contrary to the definition.

the star situated in the negative direction, is 30° or more shortly; the currents in mesh lead those in star by one-twelfth period.

As to the absolute values of the currents in the branches of the mesh, *III* shows that when the current is maximum and

$$= C_s \text{ in } O\,B$$

it is

$$= \frac{C_s}{2} \text{ in } A\,B$$

but the latter is then at one-sixth period, or 60° from its

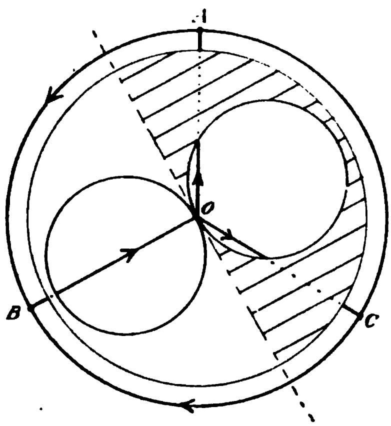

Fig. 10.

zero value. Its maximum value is therefore

$$C_m = \frac{C_s}{2\ sin\ 60°}$$

or

$$C_m = \frac{1}{\sqrt{3}} C_s = 0{\cdot}577\ C_s$$

The mean currents in the branches of the star and of the mesh are also in this proportion of 1 to 0·577.

A similar process, applied to the differences of potential, would show that those of the mesh lead those of the star by 30°.

The conservation of energy requires that the watts in the

star be equal to those of the mesh, and also that they be equal in one branch of star and one branch of mesh, since everything is symmetrical.

The voltages are, therefore, in inverse proportion of the currents.

The voltage between O and A, B or C is $\sqrt{3}$ or 1,732 times the voltage between $A\,B$, $B\,C$ or $C\,A$. This result would not be affected if there was a difference of phase between current and difference of potential, because this difference would be the same throughout. The latter appears from the fact that the relations between the currents can be deducted as above, without reference to the electro-motive force or difference of potential, and vice versa the relations between the difference of potential can be found without reference to the currents.

This fact also shows that whatever the resistances, inductances or capacities along the conductors may be, if the currents in the branches of the star (or, which is the same, in the line conductors) form a symmetrical three-phase system, the currents in the branches of the mesh also form a symmetrical three-phase system shifted by one-twelfth period relatively to the former.

It is obvious that in any symmetrical polyphased system, when the number of phases is uneven, by using each current in two opposite ways (for instance, by leading each current through right-handed and left-handed coils), the same effects can be obtained as with a system of double the number of phases. Thus a three-phase can be made equivalent to a six-phase and the five-phase to a ten-phase, but the four-phase,* since it is an even number, cannot be doubled in this manner. Moreover, as, for the three-phase, the phases in the mesh are shifted by one-twelfth period, relatively, to those in the star, the phases of the mesh come, by a similar process of doubling, exactly between those of the doubled-star currents, and this is true independently of the resistances, etc.

* Four-phase is often called two-phase, while two-phase is, strictly speaking, nothing but an ordinary alternating current.

This enables to obtain with a three-phase system, having only three line conductors, effects equivalent to those of a twelve-phase. The three-phase supersedes in this respect all others, and especially the four-phase, though the latter can also be operated with three-line wires.

A MECHANICAL ILLUSTRATION OF POLYPHASED CURRENTS.

Before going over to the comparison of the amounts of copper required in line for the transmission of power by means of continuous, alternating and polyphased currents, and to the question of measurement of energy, it may be interesting to describe a simple mechanical model by means of which most of the preceding considerations can be shown in a tangible manner. It consists (*Fig. 11*) in two discs (shown as rings of wire with spokes) mounted in such fashion that they can rock, without being allowed to turn, on their centres. Each disc is provided with a small central shaft perpendicular to its plane. A small crank is so connected to one of the shafts as to impart to it a circular conical motion around the main axis of the apparatus, which is the line joining the centres of the discs. The discs, in order to be prevented from rotating, may be connected to the frame by flat springs, or by strings (as shown), secured to their periphery and to a point of the frame situated at same level as the centre of the disc. When the crank is turned the first disc rocks evenly in all directions. and each of its points has an almost straight up and down motion, which follows the *sine* law very closely; but the different points of the periphery reach their extreme positions successively. Their motions are of different phases.

If strings of equal lengths are stretched from corresponding points of the peripheries from one disc to the other, they will have longitudinal motions following the *sine* law, and will represent the different currents (or electro-motive torces) of a polyphased system.

The second disc with its shaft, will follow exactly the motions of the first.

Fig. 11 corresponds to a symmetrical five-phase system. Any system, however, can be represented by securing the strings to corresponding points (not only at the periphery) of the discs. The second general condition of polyphased currents is expressed, in the model, by the mechanical analogon: that the centre of gravity of the strings must be on the main axis.

With a slight modification the same model can exhibit the relations between star and mesh currents.

Fig. 12 shows this for a symmetrical three-phase. Each string from the first disc carries at its end a small pulley. A

FIG. 11.

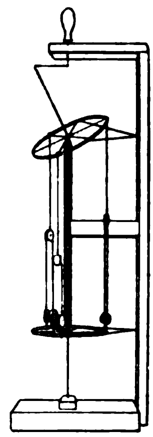

FIG. 12.

continuous string (mesh string) is led over these pulleys and over others fastened to the second disc. If now the axis of the latter be held stationary in the main axis while the crank is being operated, the first named pulleys will move up and down with the star strings, and the mesh string will have a motion of its own, which is different in phase in the different sections of this string, and also different from the motions of the star strings.

In each section the motion corresponds in phase with the current in the corresponding branch of the mesh combination, but its amplitude is double as compared with the motions of the star strings.

EFFICIENCY OF TRANSMISSION AND AMOUNTS OF COPPER.

The comparison in respect to the efficiency of transmission for a given line or to the amounts of copper required for obtaining the same efficiency, has often been made between the alternating and the continuous systems.

We might, therefore, confine ourselves to comparing the plain alternating with the polyphased systems. I will, however, recall concerning the continuous system, that the same current (measured in both cases with a dynamometer) gives the same loss by heating in the same wire whether it be continuous or alternating, as long as the frequency is not so high as to produce an appreciable skin effect.

If the alternations follow the same law for current and potential, and if there is no difference of phase between the two, the rate of flow of energy is the same for continuous and alternating transmission when current and voltage are the same and are both measured with instruments giving readings proportional to the *mean square.*

The same line will then produce equal losses and efficiencies in both cases.

But it should be remembered that, if the *sine* law is followed, when the measured voltages are the same, the *maximum difference of potential* is $\sqrt{2}$ times as large in the alternating than in the continuous transmission. Accordingly it requires twice as much copper to transmit, with the same efficiency, a given energy by alternating than by continuous currents, if the same *maximum* difference of potential is to be allowed in both cases.

It has been claimed by competent men that as far as insulation and danger are concerned, a higher *maximum* difference of potential is allowable on alternating circuits, the more so the higher the frequency. To what extent this is the case appears to be undecided yet, but it seems fair to assume that, for usual frequencies, the *measured* alternating voltage which corresponds to 100 volt continuous is comprised between

$$100 \text{ and } 70\cdot7 \left(\text{or } \frac{100}{\sqrt{2}}\right)$$

and that consequently the amount of copper required is larger

for alternating than for continuous transmission, though less than twice as large.

Whatever this proportion may really be, as everything is alternating in the polyphased systems, these doubts do not apply to the comparison between plain alternating and polyphased transmission. A difference of phase between current and electro-motive force, which would necessitate an increased amount of copper in the alternating transmission, would be just as disadvantageous in polyphased currents and would not change the relative values obtained for these two systems.

Everything being alternating, it might seem, at first, that there is no difference in the amounts of copper required for alternating or polyphased transmission with a given efficiency.

In reality, however, the polyphased systems are, gen-

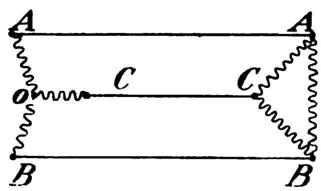

FIG. 13.

erally, more advantageous (the three-phase especially so), and this is due, broadly speaking, to the fact that the voltage on which the energy depends is not always the same as the voltage which has to be considered for insulation.

Fig. 13 represents a symmetrical three-phase, one end being a star, the other a mesh combination. *A-A*, *B-B*, *C-C* are the line conductors If we call V_e the voltage between O and A, and C_l the current (square root of mean square) in AA, we have seen previously that the voltage V_l between A and C for instance is

$$V_l = 1{\cdot}73\ V_e \tag{1}$$

and the current in AC is

$$C_m = 0{\cdot}577\ C_l$$

It is obvious that the voltage which should be considered

for insulation is V_1, because it is the highest that occurs between any two points of the system.

But the voltage on which the energy depends, together with the current C_1 in the line, is V_e.

The total energy is

$$E_3 = 3\ V_e\ C_1 \tag{2}$$

and if R_3 is the resistance of each line conductor, the total loss in transmission is

$$H_3 = 3\ C_1^2\ R_3 \tag{3}$$

For a plain alternating or two-phase system (*Fig. 14*), the

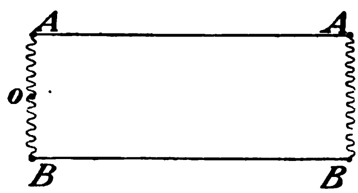

FIG. 14.

voltage *A O B* may be designated by 2 *V*, and there is no distinction to be made for insulation and energy.

$$E_2 = 2\ C\ V \tag{4}$$

$$H_2 = 2\ C^2\ R_2 \tag{5}$$

The alternating and three-phase are of same practical voltage when

$$V = 2\ V \tag{6}$$

Substituting (1) in (6) gives

$$2\ V = 1{\cdot}73\ V_e \tag{7}$$

or

$$V_e = 1{\cdot}154\ V$$

For comparing the cases where the same energy is to be transmitted with the same efficiency, we have to equalize (2) and (4); and this, with (7), gives

$$C = 1{\cdot}73\ C_1 \tag{8}$$

In the line, the currents are 1·73 times as large in alternating than in three-phase.

Equalizing (3) and (5) gives, with (8),

$$R_3 = 2\,R_2$$

This means that the cross section of alternating line conductor is twice that of three-phase conductor, and that the total amounts of copper are as 4 for alternating to 3 for three-phase.

This result, in combination with the erroneous assumption that the alternating system is as advantageous as the continuous, has led to the wrong conclusion that the three-phase is more advantageous (for equal voltage) than the continuous transmission.*

If we compare the cases in which the current density is the same for both, then

$$R_3\,C_1 = R_2\,C$$

and substituting (8) in this

$$R_3 = 1{\cdot}73\,R_2 \tag{9}$$

which, with (3) and (5), gives

$$\frac{H_3}{H_2} = 0{\cdot}866$$

The percentages of loss are as 0·866 in the three-phase to 1 in alternating when the drop of potential along the line is the same.

(9) shows that then the amounts of copper are also as

0·866 to 1

The three-phase is, respecting economy of copper, more advantageous than any other polyphased system.

Whenever the number of phases is *even*, say $2n$, the system can be considered, as far as voltage and energy are concerned, as composed of n distinct ordinary alternating currents, by taking any two diametrically opposite currents together.

* This comparison relates only to the expenditure of copper for a given voltage, leaving altogether untouched the question of obtaining or dealing more or less easily with high voltages.

The amount of copper needed is, in this case, the same as for plain alternating transmission.

When the number of phases is *uneven* there is a saving in copper, but it is the smaller the higher this number is.

So while it is twenty-five per cent. for the three-phase, it is but 9·5 per cent. for the five-phase, and so on.

The four-phase (often called two-phase) gives no saving over the alternating, as the number of phases is even, when it is used in the symmetrical manner, with four conductors.

When it is worked by means of three conductors (one being a common return, in the well-known manner), the system is unsymmetrical and the amount of copper required is even greater, as will appear from the following:

In *Fig. 15*, *OO* represents the common return wire of such a system.

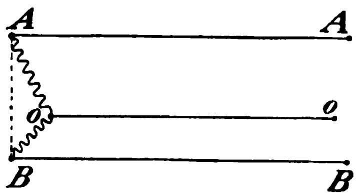

FIG. 15.

Let V_{40} be the voltage between O and A, and V_{41} the voltage between A and B, then, as the currents in OA and OB are at

$$90^\circ \text{ or } \frac{\pi}{2}$$

difference of phase and the differences of potential also. This latter, taken between A and B, will differ in phase by

$$\frac{\pi}{4} \text{ and } \frac{3\pi}{4}$$

from those in OA and OB and

$$V_{41} = 2 \sin \frac{\pi}{4} V_{40}$$

or

$$V_{41} = \sqrt{2}\, V_{40} \tag{10}$$

Correspondingly the currents stand as

$$C_5 = \sqrt{2C_4} \tag{11}$$

if C_4 is the current in AA or BB and C_5 the current in OO. The energy is

$$E_4 = 2 V_{4e} C_4 \tag{12}$$

and the loss

$$H_4 = 2C_4^2 R_4 + C_5^2 R_5 \tag{13}$$

If we assume the same current density in wires A, B and O, then

$$R_4 = \sqrt{2} R_5$$

which, with (11) and (13), gives

$$H_4 = 2C_4^2 R_4 + \frac{2}{\sqrt{2}} C_4^2 R_4$$

or

$$H_4 = (2 + \sqrt{2}) C_4^2 R_4 \tag{13a}$$

In order to compare this result with alternating transmission we have to assume

$$\dot{V}_{41} = 2V$$

and equalize (4) and (12), (5) and (13*a*), this, together with (10), gives ultimately

$$R_2 = \frac{2 + \sqrt{2}}{4} R_4$$

The distance of transmission being supposed to be the same, the weight of each conductor is in inverse proportion to its resistance, and the total weights are as

$$8 \text{ to } (2 + \sqrt{2})^2$$

or

$$1 \text{ to } 1{\cdot}457$$

for alternating and four-phase.

As a conclusion of the preceding calculations, if the amount of copper required in the line when the same practical voltage is used and under otherwise identical conditions is 100 for alternating current, it would be 75 for three-phase, 90·5 for five-phase, 70·7 to 100 for continuous, 100 for four-phase when symmetrical, and 145·7 for four-phase with common return wire.

The last named system requires, consequently, almost twice as much copper as the three-phase.

If there is a difference of phase between the currents and potentials, the carrying capacity of the conductors in respect to energy is reduced as the square of the cosine of the difference of phase. But this applies to the alternating as well as to the polyphased systems.

It appears from all the preceding considerations, I think, that the three-phase has decided advantages over the other polyphased and the alternating systems, and I will, therefore, confine my further remarks to the three-phase.

Calculations similar to the above might be carried out for determining the relative losses and the weights of copper in case of a non-symmetrical system. This would, however, be of little practical interest.

MEASUREMENT OF ENERGY.

I shall now touch the question of measurement of energy in the three-phase, but in this respect it is of actual value to consider also the general case of a non-symmetrical system having any differences of phase between the currents and potentials.

When the system is symmetrical the energy is

$$E = 3\ V_e\ C_1 \cos \varphi$$

or

$$E = 3\ V_1\ C_m \cos \varphi$$

In this case, one reading of a dynamometer gives directly the energy, but the instrument cannot generally be connected so as to give one of these results
as

$$V_1 = \sqrt{3}\ V_e$$

the energy is also

$$E = \sqrt{3}\ V_1\ C_1 \cos \varphi$$

This formula enables to work with the instrument using the current in the line and the voltage between two line conductors.

As a rule, however, the system cannot be relied upon to be symmetrical.

Messrs. Siemens & Halske have devised a method and constructed an instrument for measuring the energy in this case.*

If the currents in the three line wires are of same magnitude, then by connecting an ordinary dynamometer so that one line current, say in AA, is used, while the volt coil is connected first to A and B, then to A and C, two readings are obtained, whose sum is the total energy.

Their special dynamometer gives this same result in one reading. Its volt coil consists of two separate windings which are connected to A, B and B, C.

If the three voltages, AB, BC and CA, were the same, instead of the three currents, and this is more likely to be the case in practice, the same result would be obtained by a dynamometer provided with a double current coil and a simple volt coil.

Mr. Goerges points out that if the two above-named readings of an ordinary dynamometer are equal, this shows in the present case that there is no difference of phase between current and potential.

He shows further that the energy of any unsymmetrical three-phase can be obtained by six readings on an ordinary dynamometer or by three on the special Siemens instrument.

The above results, as well as a less complicated method, can be established by means of a very simple consideration, which proves useful also in other cases, namely:

> That any three-phase system can always be considered as consisting of two partly superposed independent alternating currents.

One is the current which passes through one line conductor, say AA, and flows back through the two others as a common return.

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* See the paper of Mr. H. Goerges, chief engineer of this firm, in *Elektrotechnische Zeitschrift* 1891, p. 212.

The second is superposed to the former in the two other conductors and does not affect the current in the first conductor.

Its value is, at any time, half the difference of the currents in B and C, while the value of the first is equal to minus half their sum.

The energy of the first is, at any moment, equal to the product of current A and the mean difference of potential between A on one side and B and C on the other; that is, half the difference of the differences of potential β and γ between $A\ C$ and $A\ B$ when taken with their proper signs.

It is twice this part of the total energy which is measured

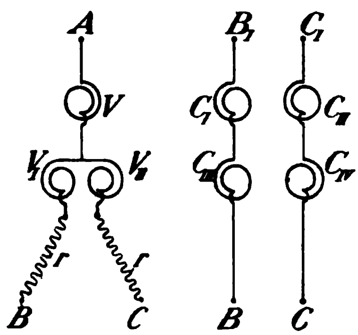

FIG. 16.

by the special Siemens dynamometer when connected as above.

The energy of the second is equal to the product of half the difference of the currents B and C and the difference of potential α between B and C.

The first part of the energy can also be measured by means of an ordinary dynamometer, whose current coil carries the current A while its volt coil is connected to A and to the middle of a resistance stretching from B to C. This resistance need not even be non-inductive, provided its two halves be equivalent.

The second part can be measured by a dynamometer which has a double current coil.

Such an instrument could easily be so arranged as to enable to measure also the first part with a proper change

of connections. The total energy would then be given by two readings.

This result expressed by formulas is

$$E = A\left(\frac{\beta - \gamma}{2}\right) + \left(\frac{C - B}{2}\right)\alpha \tag{13}$$

which is true as well for the instantaneous values as for their integral or the energy for one unit of time.

It is possible, however, to make an instrument which will combine the actions of these two parts of the energy so as to give directly their sum or the total energy.

Fig. 16 is a diagram showing the working of such an instrument. The part on the left, which may be the movable one, contains one simple volt coil V and a double one,

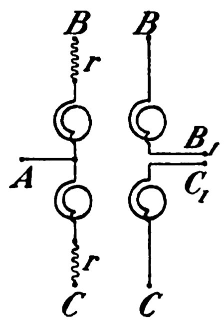

FIG. 17.

$V_I\ V_{II}$, the two halves of which are wound in opposite directions, and are connected to the equal resistances, $r\ r$.

The part on the right contains two double current coils. The halves, $C_I\ C_{II}$, of the upper one are wound both in the same way and act on coil V only.

The action is proportional at any moment to the sum of the currents B and C, or to current A.

The two halves, $C_{III}\ C_{IV}$, of the lower coil, are wound or connected in opposite directions, and act only on coil $V_I\ V_{II}$.

V_I and V_{II} being of opposite directions give no resultant action for the current which flows in V, but their actions are added for the current flowing from B to C through the

resistances r r in consequence of the difference of potential, a.

Dr. H. Aron has devised another method which is simpler yet, as it requires an instrument with four simple coils, acting in pairs, according to the diagram, *Fig. 17*.

He has modified his well-known pendulum watt counter, according to this principle, for use on three-phase circuits.

He has established this principle* by a very simple calculation, which I reproduce below.

If a, b, c represent the instantaneous values of the mesh

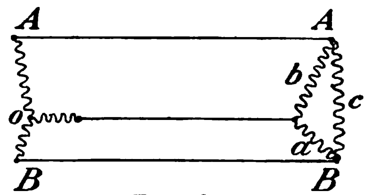

FIG. 18.

currents, *Fig. 18*, and A, B, C; α, β, γ the same as before, then at any moment the total rate of flow of energy is

$$E = a\alpha + b\beta + c\gamma \qquad (14)$$

The second condition of polyphased currents (in this case simply Kirchhoff's law) gives for three-phase

$$a - c = B \qquad (15)$$

$$b - a = C \qquad (16)$$

and the third condition

$$\alpha + \beta + \gamma = O \qquad (17)$$

If we subtract the identical expression

$$a(\alpha + \beta + \gamma) = O$$

from (14) we obtain

$$E = \beta(b - a) - \gamma(a - c)$$

which, by substituting (15) and (16), becomes:

$$E = \beta C - \gamma B$$

The two products in this equation represent the instantaneous actions of the two pairs of coils in *Fig. 17*.

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* *Elektrotechnische Zeitschrift*, 1892, p. 193.

It does not seem very natural to substract

$$a(\alpha + \beta + \gamma) = O$$

from (14), but the result can be reached equally well by writing instead of (15) and (16)

$$b = C + a$$

and

$$c = a - B$$

and substituting these values in (14), this gives:

$$E = a\,\alpha + C\,\beta + a\,\beta + a\,\gamma - B\,\gamma$$

$$E = a\,(\alpha + \beta + \gamma) + C\,\beta - B\,\gamma$$

$$E = C\,\beta - B\,\gamma$$

The same result can also be obtained by substituting in the previous equation (13)

$$A = -(C + B)$$

$$\alpha = -(\beta + \gamma)$$

which are but other expressions of the second and third conditions, this gives

$$2\ E = (C + B)\,(\beta - \gamma) + (C - B)\,(\beta + \gamma)$$

$$= C\beta + B\beta + C\beta + C\gamma - B\gamma - C\gamma - B\beta - B\gamma$$

$$2\ E = 2\ C\beta - 2\ B\gamma$$

We see thus that the measurement of energy in the three-phase system, which is likely to be the only one to come into extensive use, can be effected by one single reading of an instrument almost as simple as those used for the same purpose on ordinary alternating circuits.

The result is perfectly accurate and independent of whatever the currents and their phases may be and of however much these may differ from the phases of the electromotive forces.

For that reason the same instruments can be applied to the measurement of energy in the unsymmetrical four-phase, with three conductors (*Fig. 15*), which may be considered as a special case of the general three-phase system.

PROCEEDINGS.

[*Stated meeting, held Tuesday, September 27, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 27, 1892.

Prof. Edwin J. Houston, President, in the chair.

Present, twenty-eight members and visitors.

The minutes of the previous meeting were read and approved.

The Treasurer reported the cash balance in the treasury, and presented bills for printing, which were approved and ordered paid.

Ten nominations to membership were referred to the Committee on Admissions.

Mr. C. W. Pike proposed to amend the first sentence of Article IV of the Section's By-Laws by striking out the words *one dollar* and substituting therefor the words *two dollars*, to make the sentence read, "The annual dues of active, corresponding and associate members shall be two dollars, payable annually in advance, on the first of January of each year." [To be acted on at next meeting.]

Dr. Wm. H. Wahl read a paper describing the plant and process used by the Tacony Metal and Iron Company in electro-plating the large ornamental iron-work for the City Hall, with an aluminum alloy. In discussion thereon, Professor Houston stated that if the plating alloy were electro-negative to iron, the practical success of the operation would be very doubtful.

Prof. Edwin J. Houston read a paper on "Some Curiosities in Early Electro-therapeutics." Referred for publication.

Mr. W. N. Jennings exhibited, by projecting lantern, and described, some photographs of lightning taken by him from a rapidly-moving train on the prairie of North Dakota at midnight, August 8, 1892. The first and second, taken broadside from a car window, showed single and double discharges, and telegraph poles in triple outline. The third, taken from the rear platform of the train, showed a single discharge with buildings in quadruple outline. The fourth showed a wonderful discharge in the form of a broad band which was called "sash lightning." All of the photographs seemed clearly to prove that lightning is an oscillatory motion; Mr. Jennings also showed several photographs of "coronal" electric discharges taken in April, 1889; and outlines of Holtz machine sparks, made directly on photographic plates, without the use of a camera. All of these excited much interest and were discussed at considerable length.

The meeting then adjourned. L. F. RONDINELLA, *Secretary*.

SOME CURIOSITIES IN EARLY ELECTRO-THERAPEUTICS.

BY PROF. EDWIN J. HOUSTON.

[*Read before the Electrical Section of the Franklin Institute, September 27, 1892.*]

The astonishing physical effects produced by the discharge of the Leyden jar through the human body, led not only the general public, but also the medical fraternity, shortly after its discovery in 1745, to form the most absurd ideas concerning the curative powers of electricity.

The wildest claims were made concerning the efficacy of the electric discharge for the curing of disease. Claims that were at first unhesitatingly accepted as true were soon found in actual practice to fail of realization.

That *bona fide* results in the way of actual cures were obtained in some of the early applications of electricity to the curing of disease appears to be beyond doubt, for the method of treatment in some cases remains practically the same to-day as it was at the time of the discovery of the Leyden jar. Then, again, in those days, as at present, the public's natural credulity led it to perhaps lay more stress on the few cases that were cured than on the more numerous cases that either failed to receive any benefit from the treatment or were actually killed by it; or, putting the same thing in another way, the people who were cured gave glowing certificates of their cures, while the people who were killed gave none.

I have thought that it might interest you if I brought before you a few curiosities in the way of the astonishingly absurd statements that were put forth about the time of the discovery of the Leyden jar, as to the ability of the electric force to cure.

Unfortunately, I have been called upon to read this paper at an extremely short notice, and must, therefore, ask you to take, in many cases, my recollections of matters that I

have read a number of years ago, in place of actual quotations from the original records.

Far be it from my purpose to throw any discredit on the medical fraternity as it existed in the latter part of the eighteenth and the beginning of the nineteenth century, or to throw any doubts on the value of electro-therapeutics as practised at the present day; for the great value to be derived from the intelligent application of electricity for curative purposes is no longer a matter of doubt.

In criticising some of the ideas presented in electro-therapeutics, at the time of the discovery of the Leyden jar, it should be remembered that it is, of course, much easier to find fault with methods than to propose better methods; and when we remember the comparatively limited knowledge the world had acquired concerning the nature of the electric force at these early times, and the belief that was quite common in the scientific world concerning the presence of various effluvia, which were supposed to be capable of passing through the densest matter, we should criticize less harshly some of the beliefs put forward at these early times as to the proper method of applying electricity to the curing of disease. Indeed, an examination of the advertisements of some so-called medical electricians made even in these latter days, would unearth absurdities far more marked than those of the time we are discussing.

I once read in a circular letter issued, if my memory serves me correctly, some fifteen years ago, by a certain so-called medical doctor, in which he claimed among other advantages for the peculiar kind of electricity which he claimed his apparatus was capable of producing, that it was electricity of the corkscrew or gimlet type, and that it, therefore, had but little difficulty in insinuating itself into all parts of the body, so searching out the disease. Or, taking a time not so modern, when a certain inventor, I think, by the name of Edward Craddock Monckton, an exceedingly ingenious man by the way, who has taken out scores of electrical patents, and among others a method of electrically joining articles of jewelry, gravely proposes in

a British patent, to so connect the body of a healthy animal, like a cow for example, with that of the patient to be treated, as to electrically convey the health and strength of the animal to the patient. To do this he places the body of the cow, or other animal, upon an insulating stool, and connecting it to that of the patient to be treated by electric conductors, passes the current of a battery through the animal and subsequently through the body of the patient and thereby, as he claims, conveys to the patient the vitality of the animal.

Passing these aside, however, I would call your attention to a few curiosities in early electro-therapeutics.

It was believed by many of the early practitioners that the virtues of a drug could be readily caused to pass through glass vessels by means of electric discharges. This belief was probably founded on the rather prevalent belief at this time as to the existence of effluvia. The attraction of a magnetic needle by a magnet, notwithstanding the interposition of a plate of glass, was at one time explained on the supposition of effluvia passing out of the magnet and through the glass into the iron. It is not, therefore, surprising to find such statements as that of a Dr. Bruni writing to Dr. Watson of a remarkable case in which, as he claims, medicine shut up in a tightly sealed glass globe produced its peculiar effect on a person who was electrified by the use of said globe. I mention this as a particular case, although the early records of electricity are filled with similar cases. What Dr. Watson has to say about these experiments will, I think, interest you, and I will, therefore, give you the following quotation:

"Dr. Bruni gives me next in his information from Rome, which is, that a gentleman there covered the internal surface of a glass cylinder (which some use instead of a globe) with a purgative medicine; and that man, electrified therewith, found on the spot the same effect as if he had swallowed the medicine. He then recommended to us, in England, to try how far the electric power may be of service in distempers.

"These cases, and particularly the last, as it may to some

appear extravagant and whimsical, I should have been cautious of bringing before the Royal Society, had you not judged it proper they should be added to those similar accounts from other places, which were read to us last meeting. I think neither myself nor Dr. Bruni answerable for the truth of these facts, as we relate no more than we have received. In truth, all the phenomena in electricity are so wonderful that it is scarcely prudent to deny the possibilities of any accounts concerning it till we have made experiments carefully ourselves. We are very sure it is possible to render a living body replete with electrical effluvia, or to transmit and send such effluvia through a living body, in a stream, as long as we think proper: we are not sure that it is impossible for these effluvia to convey with them into that living body the most subtile and active effluvia of other substances; and if they can do so, the effects suggested are not wholly improbable, for several experiments have proved that a very minute quantity of medicine, transfused directly into the blood and circulating fluids, will have the same effect as a large dose thereof taken into the stomach."

Somewhat similar to the effect just referred to was the belief that the odors of certain substances, placed in tightly sealed glass globes, could be detected by sending electric discharges across them; or the similar belief that highly poisonous substances, placed in such glass globes, could produce deleterious effects on people when electric discharges were sent through the glass globes.

In the *Encyclopedia of the Arts and Sciences*, published in 1798, the following account is given of the so-called medicated tubes:

"It was asserted by Signor Pivati at Venice, and after him by Verati at Bologna, Mr. Blanchi at Turin, and Mr. Winkler, at Leipsic, that if odoriferous substances were confined in glass vessels, and the vessels excited, the odors and other medicinal virtues would transpire through the glass, infect the atmosphere of the conductor, and communicate the virtue to all persons in contact with it; also, that those substances, held in the hands of persons electrified, would communicate their virtues to them; so that the

medicine might be made to operate without being taken into the stomach. They even pretended to have wrought many cures by the help of electricity applied in this way. To see the wonderful effects of these medicated tubes, as they were called, Mr. Nollet travelled into Italy, where he visited all the gentlemen who had published any account of these experiments. But tho' he engaged them to repeat their experiments in his presence, and upon himself; and though he made it his business to get all the information he could concerning them, he returned fully convinced, that in no instance had the odors been found to transpire through the pores of excited glass, and that no drugs had ever communicated their virtue to people who had only held them in their hands while they were electrified."

Franklin made a study of the effects of the so-called medicated tubes. In his *Experiments and Discoveries in Electricity*, published in London in 1769, he says on page 82:

"Hence we see the impossibility of success in the experiments proposed, to draw out the effluvial virtues of a non-electric, as cinnamon for instance, and mixing them with the electric fluid, to convey them with that into the body, by including it in the globe, and then applying friction, etc. For though the effluvia of cinnamon and the electric fluid should mix within the globe, they would never come out together through the pores of the glass, and so go to the prime conductor, for the electric fluid itself cannot come through; and the prime conductor is always supplied from the cushion, and that from the floor. And besides, when the globe is filled with cinnamon, or other non-electric, no electric fluid can be obtained from its outer surface, for the reason before mentioned."

In an article entitled "A New Discovery of the Usefulness of Electricity in Medicine," by John Henry Winkler, read before the Royal Society by Mr. Watson, March 31, 1748, and published in abstract on page 399 of Vol. X of the *Philosophical Transactions*, we find the following statement:

"Electricity has a power of dividing subtilely. It carries off with it the parts of those bodies which it dissolves, and transfers them to those parts where the electrical sparks

appear. If odorous substances are ever so closely confined in glass vessels, it so divides them that their exhalations penetrate the glass as easily as magnetical powers, and flow like a river thro' the atmosphere of cylinders and chains, to which the electricity is communicated. The electrical matter which comes out of the extremity of the cylinder, gives an aromatic odor to the hand that touches it. But the odor communicated does not stop in that part of the body on which the electrical river has flowed, but with a continued aspiration pervades the whole human body. Not only the skin and garments are scented, but even the air breathed by the lungs, the spittle, and the sweat of the person affected smell of aromatics, which are agitated by electricity in the closed vessel."

So also the following account of a similar use on page 400 of the same *Transactions* :

"About the beginning of the present year, 1748. I received a letter from Venice, which greatly confirms this conjecture. The author, Joannes Daniel Gaifel, related an affair which surprised all the learned of Venice, Bologna and other cities of Italy. It was accompanied with a printed epistle in Italian, written by an eminent person at Venice, Sig. Jo. Franc. Pivati. In this epistle, the subject of which is medical electricity, he relates a story of wonderful effects to Sig. Fr. Maria Zanotti, Secretary of the Academy at Bologna; and the art, by which these were performed, was the invention of Pivati. A manifest example of the virtue of electricity was shown in the Balsam of Peru, which was so concealed in a glass cylinder, that before the application of electricity there could not be the least smell of it by any means discovered. A man, who having a pain in his side, has applied hyssop to it by the advice of a physician, approached to the cylinder. The man was electrified by it, went home, fell asleep, sweated, and dispersed the power of the balsam. His clothes, bed, chamber, all smelt of it. When he had refreshed himself by this sleep, he combed his head, and found the balsam to have penetrated his hair, so that the very comb was perfumed. The next day S. Pivati electrified a man in health after the same man-

ner, who knew nothing of what had been done before. On his going into company about a quarter of an hour afterwards, he found a gradual warmth diffusing itself through his whole body. He grew lively and more cheerful than usual, His companions were surprised at an odor, and could not imagine whence it proceeded, but he himself perceived that the perfume arose from his own body, at which he was much surprised, not having the least suspicion that it was owing to the operation that had been performed upon him by S. Pivati."

Another equally curious early practice consisted in the use of what might be termed medicated Leyden jars, in which the inner coating of a Leyden jar, through which discharges were given, was formed of or contained liquids, consisting of aqueous solutions of various medical substances. On the discharges from such jars being passed through a patient's body, it was believed that the peculiar effects of the medicine dissolved in the liquid placed inside the jar could be experienced.

Of a similar nature is a rather extended belief which existed at one time as to the effects produced by sending electric discharges through solutions of medicine prior to their being taken into the system,

In a British patent, 991 for 1862, Frederick William Breary describes improvements in medicated cups, which consist practically in sending electric currents through the medicines contained in such cups prior to their being taken into the body. I will quote from the specification of this patent:

"The third improvement of my said invention consists in the formation of similar cups or vessels in and by which the principle of galvanic action is obtained either in combination with the medicinal qualities above mentioned or otherwise. The drinking vessel formed upon this principle I denominate the improved medicated 'galvanic cup.'

"In applying the above-mentioned improvement to my said invention, I make a cup or other suitable vessel (for drinking or other purposes), also in two or more parts, and either form the same on either of the medicated principles

above described, or otherwise, as may be required, and to fix or insert therein a voltaic or galvanic pile, and galvanize or medicate the water or other liquid placed therein by slightly acidulating the same. By preference, however, I form the foot, stem. and outer bowl of these cups or vessels of glass, china, or other non-conducting material; having three or more water tight cells or compartments therein, separated one from the other. I make the centre compartment occupy nearly the whole of the internal space, and make the two side compartments small, but sufficiently large to contain the galvanic media. The latter compartments are closed at the top by means of movable stoppers; the central compartment is made open for containing the medicated water or other liquid to be galvanized. The internal surfaces of the central compartment I line with metal or mineral on one part, and with wood or vegetable, as before described. Extending across this compartment, and forming a metallic connection between the two side cells, I fix a bar or perforated plate of metal. When using this galvanic cup, the water or other liquid is first placed in the centre compartment, where it is medicated; then by filling the side compartments, one with granulated copper and fine sand, and the other with granulated zinc and fine sand, and adding to each a little acidulated liquid, the galvanic essence will pass or flow along and over the metal bar or perforated conductor through the medicated water or liquid, and will impart its medicinal virtues to the same, and thus a combined medicated and galvanized action will be obtained."

PROCEEDINGS.

[*Stated meeting, held Tuesday, October 25, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 25, 1892.

Prof. Edwin J. Houston, President, in the chair.

Present, thirty-four members and visitors.

The minutes of the previous meeting were read and approved.

The Treasurer reported the cash balance in the treasury, and presented bills for printing and clerical work, which were approved and ordered paid.

The Committee on Admissions reported ten elections to membership since last meeting. Two nominations were referred to this committee.

The first sentence of Article IV of the Section's By-Laws was amended to read, "The annual dues of active, corresponding and associate members shall be two dollars, payable annually in advance, on the first of January of each year."

Mr. Elmer G. Willyoung exhibited "A New Ballistic Galvanometer," and read a paper describing it. The instrument is made by Queen & Co., its principal features being the composite coils consisting of about five different sizes of wire forming portions of the coils, whose shapes are obtained by careful calculation for best effect; the magnetic system consisting of four bell magnets, the lowest one carrying a movable ring, by means of which the sensibility of the system can be varied without using a controlling magnet; and the quartz fibre suspension. The paper was referred for publication.

Mr. Paul A. Winand read a paper "On the Measurement of Energy in the Three-Phase System," in which he described the best methods of obtaining correct results. Referred for publication.

A communication was read from Mr. E. G. Willyoung inviting the Section to visit the Electrical Laboratory of Queen & Co., at Ardmore, Pa., and upon motion the chair appointed Messrs. E. A. Partridge and Rondinella a committee to make the necessary arrangements.

The meeting then adjourned.

L. F. RONDINELLA, *Secretary*.

A NEW BALLISTIC GALVANOMETER.

(*a*) WITH HIGH INSULATION, GRADED COILS, AND OTHERWISE CONSTRUCTED CLOSELY TO THEORY.

(*b*) WITH A NEW METHOD OF VARYING THE SENSIBILITY WITHIN THE WIDEST LIMITS WITHOUT THE USE OF A CONTROL MAGNET.

BY ELMER G. WILLYOUNG.

[*Read at the stated meeting of the Electrical Section, Tuesday, October 25, 1892.*]

(*a*) The galvanometer which I am about to present to your notice is not, as are many instruments, the result of chance development, but represents the fulfilment of deliberate intention aided by close application of theory and experimental data systematically obtained for the purpose. Some six or eight months ago it became necessary for the firm with which I am connected to place upon the market a good ballistic galvanometer, and I accordingly set about to design and build such an instrument. After a little time spent in looking over a number of combinations and general styles advocated by various persons, and in pondering different theoretical considerations, I designed an instrument somewhat similar to that which you see. (*Fig. 1.*) This first instrument, when completed, was taken in hand at the laboratory and thoroughly tested under a large variety of conditions: its law of deflection, its leakage, the decrements of damping with coil frames open and closed; with coils short-circuited, and in series with various resistances, were all found.

Various modes of suspension and of constructing systems were also tried. In particular, a considerable time was devoted to a study of different methods of varying the sensibility of the system and some important conclusions were drawn. After this earlier and systematic study of the instrument it was placed in the laboratory, and used for the

regular daily work of determining battery curves, condenser capacities, making hysteresis determinations, etc., which naturally make up the routine of a working laboratory. After some weeks of work of this kind and accompanying "unconscious cerebration" of the writer, and of one of his associates, Mr. Northrup, who made most of the systematic tests first referred to, the matter was again taken up, a modified design produced, and the instrument constructed which you see here. I will first refer to more general points which are to be noticed.

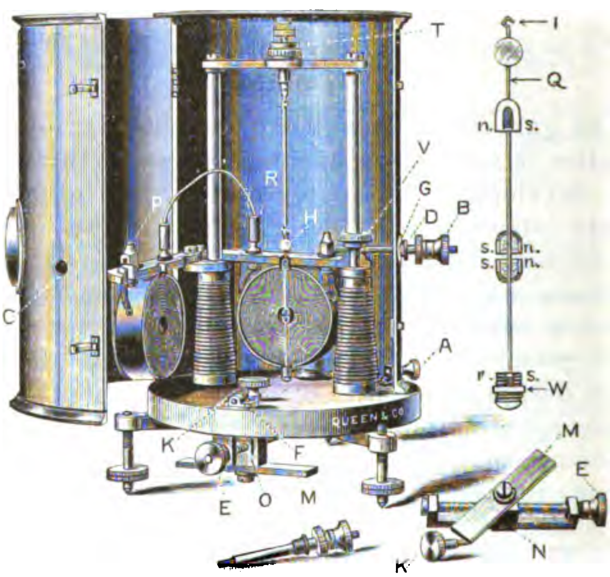


FIG. 1.

To speak of the general plan of the instrument for a moment, the coils are two in number and equal in size; they close upon the magnetic system, which hangs in a diameter between them, and are supported upon highly polished and corrugated hard rubber pillars. These pillars are two and seven-sixteenths inches high, and, since the corrugations are sides of equilateral triangles, they are equivalent to plain pillars of just twice the surface or about five inches high. The surface resistance to leakage is, therefore, very great. Upon the rubber pillars are brass rods joined at the top by

a cross bar, which carries the torsion head and its suspension. The suspension is, when in position, a trifle over two and three-fourths inches long. The torsion head is divided into 15° divisions, and by its means the coëfficient of torsion of any suspension may be quickly obtained. I want to call particular attention to the coils of this galvanometer; in this regard the instrument has been as closely conformed to theory as possible. It is, of course, a fundamental fact of galvanometer theory that the electro-magnetic effect of a coil upon a magnet is directly proportional to the number of turns in the coil, and hence, in a very sensitive instrument, the windings must be as many as possible; a moment's thought, however, makes it clear that there is a practical limit to the number of turns which may be used, and that this limit is reached when the coil has obtained such a diameter that the loss of electro-magnetic action due to increased resistance is equal to the gain effected by the extra turn. In this we are assuming that but one size of wire is used in the winding; if now we increase the cross-section of the wire suitably we may still increase efficiency by adding turns, and this to an indefinite extent by continuing to increase the cross-section as a function of the increased diameter; by doing this, however, the coil would soon become of unmanageable proportions. It can also easily be shown that the exterior bounding surface of a galvanometer coil, for maximum effect, is a surface of revolution the equation of whose meridional section is $u^2 = c^2 \sin \theta$ where c is a constant.* The form of this curve is shown in *Fig. 2*, which represents a meridional cross-section of a properly-shaped coil, where there are several curves based on different values of c. It is obviously not commercially possible to vary the wire as continuously as rigid conformity to theory would require, as this would mean a continuous wire tapering uniformly from one end to the other; instead of this we may, however, obtain an approximation to theory by changing the sizes of wire used a greater or less number of times. This is what

* Maxwell's *Elec. and Magnetism*, Vol. ii, p. 361 (3d ed.).

has been done in the coils before you,* and, indeed, is what is being done now in all galvanometers made by our firm. The usual number of changes which we make is five, and that number has been employed here. Galvanometer coils wound in this way are called "graded" coils. In effecting this grading we first decide upon the total resistance of the coil and then by an application of the mathematical theory, as given in Maxwell, determine the exact diameters of the wires which must be used and the positions and shapes of their bounding surfaces, the latter, of course, satisfying the equation $u^2 = c^2 \sin \theta$. The labor involved in making these calculations is considerable, as the insulation thickness of the wire is a complicating factor which must be allowed for; it is, in fact, necessary to obtain the final result by a series of approximations of at least three in number, first substituting an approximate value of δ, the ratio of insulation thickness to the radius of the bare wire, from which we obtain an approximate value of this bare wire radius; we then substitute a more correct value of δ and solve again and at last use the nearest gauge number to the obtained diameter. We do not, of course, work all these calculations out every time we wind a pair of coils, as that would not be commercially possible. Our coils on all our galvanometers are of the same size, or rather are reduced to several standard sizes and gauges are used for each size. Consequently we have been enabled to work out the complete winding for each size of coil for every resistance likely to be desired from one-half ohm to 10,000 ohms; we have a typical drawing, properly lettered, and all that is done is to wind wire until the bounding curve of the wire surface calipers to the determined data.† I have here (*Fig. 3*) one of the forms upon which the coils are wound. We have a number of these for each of the two or three types of coils, all of each type being rigidly the same size. They are made so that after a coil is wound the sides and core can readily

* A specimen coil, wound and ready to slip into any galvanometer frame, was here shown.

† This typical drawing was here shown together with the table of calculated data accompanying it from which coils are actually wound.

be slipped away. The core is of steel, in order that it may be very small and yet be of sufficient strength. Note the peculiar curve (*A*, *Fig. 3*) at one side; this is a mathematically determined curve, and is so shaped as to secure the maximum action upon the needle of the windings lying close to the magnets. Here is a wound coil ready for slipping into the frame; I think you can all see the lines of separation of the various windings, and that they have a greater diameter upon the one side than upon the other. In the pair of coils used in this instrument the space surrounding the magnets has been made very small, so as to make use of the exceedingly valuable space lying close to the centre. To show the practical advantage of grading coils, if the coils of this

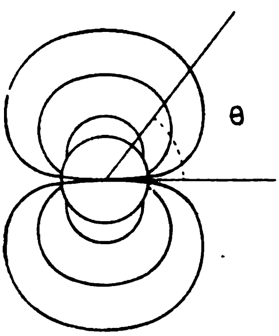


FIG. 2

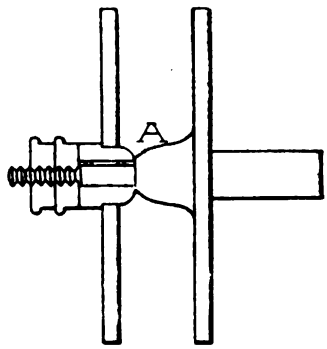


FIG. 3.

galvanometer had been wound to the same resistance with but *one* size of wire, and occupying the same volume, the sensibility would have been but four-ninths as much. The difference in cost is very inconsiderable.

The clearance between the coils in this instrument is but one-twentieth of an inch, leaving only just enough room for the shaft of the system to work freely. The coils may be used in any way desired, either singly or in series or in multiple, thus giving one three instruments in one, *e. g.*, the present instrument is of about 5,000 ohms resistance with the coils in series; using either coil singly the resistance is 2,500 ohms and in multiple 1,250 ohms. The various connections are quickly made by means of the

little plug tipped flexible cords (*R*, *Fig. 1*), which plug into little receptacles *P* on the coil frames. In case a greater range even than this is desired, the coils are made interchangeable and may readily be removed from the instrument by simply loosening one screw on each frame. The binding posts *B* are placed at the extremities of brass rods which pass through the case and screw upon lugs attached to the coil frames; where the rods pass through the case, the case holes *G* are bored somewhat larger and a rubber collar *D* fits upon the rod and fills up the holes in the case, keeping out dust and dirt; when the instrument is to be used the collars are drawn back so that there is no possibility of leakage taking place through the case, and the entire instrument is still supported by the corrugated rubber pillars.

It will be noticed that there are no levels upon this instrument; they are left off purposely. I don't know that I had ever seen a good galvanometer without levels attached until I began to leave them off of our instruments. I had never questioned the utility of them while I was simply a user of apparatus, although I never made any use of them myself, but when it became a matter of business and my attention had to be given to the subject of designing the best for the lowest cost, I soon came to look upon the level as an utterly superfluous appendage. Theoretically, of course, the level has been upon the instruments for the purpose of adjusting them *to* the system, so that when the bubble was in its proper position the system would hang perfectly free; practically, however, the clearance allowed in a good galvanometer is so small that the slightest lack of perfection in the adjustment or change of position of the torsion head would cause the system to stick; the smallest hair or shred of insulating material or stray fibre would operate in the same way, so that actually the user has always found it far more convenient to level the instrument up by means of the levelling screws, until, by observing the mirror, the system was seen to swing free. If this was not easily attained the coils would be swung apart, and the system and faces of the coils closely inspected to ascertain the

cause of difficulty. I have inquired of many experienced users of these delicate galvanometers, and have always received the same reply, viz: that they never thought of using the levels and found them entirely unnecessary, thus confirming my own experience. In order quickly to inspect the system, the coils are pivoted so as to be easily thrown open by merely removing the binding post rods and raising

FIG. 4.

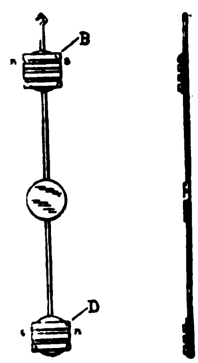


FIG. 5.

the milled screw clamp *V*. In practice the first coil only is swung away.

(*b*) Having thus described the more general characteristics of the instrument, I want to speak more particularly of an improvement in galvanometers having moving systems composed of magnets which has been devised in our laboratory and applied for the first time in this form of instru-

ment. The improvement consists in a means of varying the sensibility of the instrument within the widest limits in an exceedingly simple way, and in a manner which entirely does away with some of the annoying inconveniences and sources of inaccuracy which have been experienced heretofore when using instruments of this character. The usual method of varying the sensibility of galvanometers of this kind has been, as is well known, by neutralizing to a greater or less degree, the influence of the earth's field upon the system by means of a control magnet suitably placed upon the instrument. This magnet has usually been placed upon a standard attached to the instrument and rising from its centre above as in the galvanometer shown in *Fig. 4*. Occasionally this magnet has been placed below instead of above, and in one or two patterns at the front or back. This magnet could be raised or lowered to change the intensity of its field at the needle, or oriented, in order to change its plane; occasionally, also, a means of changing the intensity of the control or its plane without moving it to or away from the needle has been employed.* All these plans have been somewhat expensive to use, and all, except the last, have been open to the objection that they could not be used without jarring and disturbing the instrument. But the most serious difficulty has been due to an entirely different cause, which I will endeavor to point out. Let us conceive of the case of a system composed of two sets of magnets, *B* and *D*, *Fig. 5*, the upper set composed of four magnets with their north poles pointing in one direction, and the lower set composed of three magnets of the same length as the upper set, and with their north poles pointing in the opposite direction; this combination is known as an "astatic" system, since the controlling force of the earth's field is only the *difference* of the magnetic moments of the two systems. In the case supposed, the upper set "controls," and the north poles of the upper system will point to the north. If now we wish to make the system still more astatic we weaken the earth's field upon the upper needle by means of

* See Kittler's *Handbuch der Elektrotechnik*, pp. 226, 227, 228, Vol. i, 1886.

a control magnet suitably placed near it.* We now have the magnetic system subject to the influence of two fields, one the earth's and the other the field of the control magnet. We may represent these two fields in strength and direction by lines suitably drawn; let us also suppose that these fields are placed to oppose one another, but with planes not rigidly parallel. *Fig. 6* (*a*) shows this with *A B* representing the earth's field in strength and direction, and *A C* that of the control magnet. Completing the parallelogram we obtain *A D*, which represents the resultant field in direction and intensity. Let us suppose, now, that the earth's field slightly changes in direction, as is shown in (*b*) *Fig. 6.* The resultant now point, nearly directly opposite to its first position, and though the earth's field has moved through but an exceedingly small angle, we see that the resultant

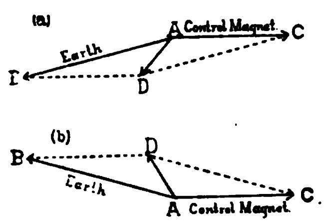


FIG. 6.

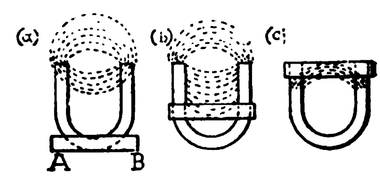


FIG. 7.

will have moved through nearly 180°, so that the slightest shifting of the earth's meridian causes an immensely magnified movement of the resultant. This theoretical conclusion is thoroughly realized in practice, although but few who are annoyed by it are aware of its cause. It is, of course, seen that this magnification varies with the sensibility and is largest when the instrument is most sensitive. In galvanometer work this phenomenon is known as the "drift" of the needles, and the tyro in galvanometer practice is very apt to think his instrument bewitched for some time after

* This is the method which has always been employed in instruments which have been used; it is, however, not theoretically the best way, which would be to place a standard at right angles to the earth's meridian and midway between the sets of magnets, and place upon this standard a control magnet, rotating upon it in a plane at right angles to the standard; its horizontal component would vary with its phase.

making its acquaintance. There are none of us, probably but who have experienced it; we work at an instrument, adjust the telescope and get the mirror nicely on zero. In a few minutes we look again and find some other number of the scale before us, and if we watch for a time, we may see the scale travelling along the mirror, until often it disappears entirely, the mirror having entirely left it; if we let it alone it will very likely come back later in the day and go in the other direction. The mirror is never still, going now one way and now another, though more stable during some parts of the day than at others. This is apt to be a very serious hindrance in making exact observations when the instrument is very sensitive, as when the mirror fails to return to zero after a deflection we are unable to tell definitely whether this is due to the cause just mentioned or to some other, and, if the former, as to just how much must be added to or subtracted from the observed deflection on this account. It also necessitates frequent re-adjustment and hence, re-determination of the constant of the instrument to prevent the mirror going entirely off the scale. I will now explain the improvement embodied in this instrument, and now for the first time made public. The device is the invention of Mr. E. F. Northrup, of Queen & Co.'s laboratory, and I regard it as one of the most important additions to galvanometer practice which has been made for many years. By its use all the annoyances of "drift" are eliminated and the instrument rendered much more certain in its indications besides being less costly to manufacture. Reference to *Fig.* 7 will show the principle of the device; *M* is an ordinary horseshoe magnet at the bend of which is a bar of soft iron *A B*; the distribution of the lines of force is practically unaltered by this bar. In (*b*) we have the same magnet, but with the bar moved about half-way up towards the poles; the lines of force are now considerably deformed, and many have been drawn down so as to pass through the soft iron armature. In (*c*) the armature has been pushed up to the very poles, and almost all the lines are now passing through it, the magnet thus being short-circuited and made about as ineffective, as regards its exter-

nal field, as would be a mass of soft iron of the same shape. Now, let us look at *Fig. 8*, which represents the system used in this instrument. The system is seen to be composed of four "bell" magnets of the well-known Siemens type; the upper and lower have their poles turned in the same direction while the centre magnets have their poles also in the same direction but opposite to that of the outside magnets. The upper and lower magnets thus make up one set of an ordinary astatic system, and correspond with

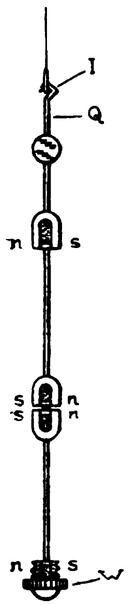


FIG. 8.

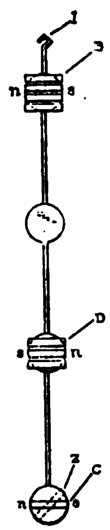


FIG. 9.

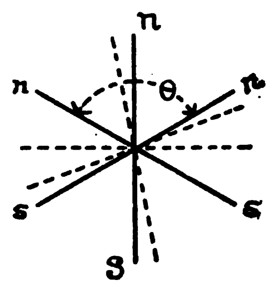


FIG. 10.

the set *B*, *Fig. 5*, while the centre magnets correspond with the set *D*. The outside magnets are, as will be noticed, slightly longer than the inner ones, and will, consequently, if all are magnetized in practically the same way, be the stronger, and will "control" the system. If now we weaken one or both of these outside magnets their control will be lessened, and the period of the system will be increased, until finally the influence of the inner magnets will begin to predominate, and the system will swing round through 180°. The means by which this weakening

is accomplished are in this instrument very simple. The lower magnet has cut upon it a very fine screw thread, and upon this thread is fitted a narrow and light ring of soft iron *W*. When the ring is at the bottom of the magnet its influence is *nil*; if we desire a greater sensibility we simply screw the ring up until this sensibility is attained. In order to do this easily, the system is attached to the fibre by means of an exceedingly small hook *I*, and may readily be removed by simply lifting it off with the aid of a small pair of forceps when the ring may be moved a trifle, the system replaced and the vibration period observed. In practice all this can be done in a very few minutes. It might be objected that in thus "short-circuiting" this outside magnet we lose a portion of the deflecting moment of this magnet, which is, of course, acted upon by the coil. This is true but the loss is very small, the effective couple of these outside magnets being vastly less than that of the inner. The best proof, however, is the result, and here are some of the results obtained with this instrument. Using the old method of control, *i. e.*, an exterior control magnet, we had:

Period (single swing),	$4\frac{1}{2}\frac{7}{8}$ seconds.
Mean deflection $\frac{1}{5}$ M. F. at 1·44 volts,	100 mms.
Drift in 5 minutes,	2·5 mms.

With Northrup's method:

Period (single swing),	$11\frac{1}{10}$ seconds
Mean deflection $\frac{1}{5}$ M. F. at 1·44 volts,	211·5 mms.
Drift in 5 minutes,	Inappreciable.

And making still more astatic:

Period (single swing),	21·6 seconds.
Mean deflection $\frac{1}{10}$ M. F. at 1·44 volts,	237 mms.
Drift in 5 minutes,	Inappreciable.

The large vibration period of over forty seconds for a complete swing obtained without "drift" is extraordinary in my experience; it may readily be made much greater, however, and the instrument correspondingly more sensitive if desired by this method. I have here a system made in the same way as the one in the instrument before you, but larger, so that I may illustrate the working of this

device. It is hung by a silk fibre with the short-circuiting ring at the bottom, and the system is as insensitive as it can be made with the outside magnets controlling. I start it vibrating, and we note that the period is very short, something like three seconds (*s. v.*). I now screw up the ring about four turns and you will notice that the period is considerably lengthened and is now about ten seconds (*s. v*). Now, it is about twenty seconds (*s. v.*), and by screwing it up further I can completely reverse the plane of the system; if I continue to still further weaken the lower magnet I shall obviously make the system less and less sensitive, since the centre magnets will control more and more strongly. Instead of screwing this ring on we may, of course, merely slip it on, allowing it to hold by its own friction only. We may also apply it to the upper instead of the lower magnet, or to both if we desire. The application of this same method to the orthodox light system is obvious and may be made in a variety of ways. *Fig. 5* represents in diagram such a system as used in the Thomson four-coil galvanometer as made by us, and *Fig. 9* the system as it might be modified to use Northrup's device. Here there are two sets of magnets, *B* and *D*, which would lie in the centre of the upper and lower pair of coils, respectively.

To use the new device we make the shaft of the system long enough to extend down a little below the bottom of the lower coil and place upon it an extra magnet *C*, as shown in the figure, with its poles placed in the same direction as those of the upper set. At the back of this little extra magnet we pivot a small piece of soft iron *Z*, of about the same size and shape as the magnet, so that it may be rotated to be either perpendicular or parallel to it. When in the former position, the little extra magnet is allowed to assist the upper set which consequently controls; when in the latter, the extra magnet is short-circuited, and the influence of the lower set of magnets, being a trifle longer, predominates. The weight added to the system by this construction may be so small as to be inappreciable in all except the most delicate instruments. We ourselves, however, have not yet adopted this device as applied to very light and small

systems, on account of the excessive delicacy of construction involved and of lack of time in which to work this out with thoroughness. The necessary delicacy of such a "light" system is so very great,* mechanically, that I have doubts as to whether the device had best be applied to such. In the instrument before you, I use an exterior control magnet when the light system is used. This magnet you see in position upon the base (*Fig. 1*); a middle head *E* works a screw through a block *O*, so that the position of the magnet with reference to the system is easily varied. When the ballistic system is used, this magnet is easily removed by unscrewing the small head *K* upon the upper part of the base.

The general construction of the system used in this instrument is well worth looking at, as considerable pains have been taken to work out one thoroughly adapted to the requirements. As is well known, a perfect ballistic system must have so large a moment of inertia that the entire quantity of electricity which it is designed to measure must have time to pass through the coils before the system is able to move. In addition it must be so shaped as to have a minimum damping either of air friction or magnetic or otherwise. To avoid air friction, the system must be of small diameter and shaped so as not to scoop and carry air before it and it must be very heavy in order to give it the required large moment of inertia. This system, I think, thoroughly conforms to all the requirements. The magnets are cylindrical bell-shaped magnets of but thirteen-sixty-fourths inches in diameter and are threaded upon a shaft of quartz rod; in order to make them very heavy they are filled with small fragments of lead, held in place by means of a little hard wax; after being filled thus a little brass washer is placed in the end of each magnet with the shaft passing directly through its centre; this is for the purpose of holding the magnets in place in a perfectly symmetrical manner. The whole weight of this system is 4·5 grammes. It is

* A light system, as made by us for Thomson reflecting galvanometers, weighs somewhat less than 350 milligrammes.

made with a small hook, *I*, above, so that it can be quickly unhooked from the fibre for adjustment or to be replaced by another kind of system. The fibre also hooks into place and can be quickly removed in correspondence with the system which is to be used. For the most delicate work the use of hooks introduces a slight error as the two hooks will "ride" upon one another through a very small angle and thus the system will deflect without torsion of the suspension. In such cases a small drop of hot beeswax touched to the hooks will cement them together in a perfectly satisfactory manner, and they are readily separable again by touching for an instant with a warm iron or brass wire.

The suspension itself of quartz and is about $\frac{7}{10000}$ of an inch in diameter; quartz is used because it has absolutely no set whatever, a statement which is true of no other suspension, metallic or otherwise, of which I have knowledge, its elasticity is almost perfect through extremely large limits. According to Professor Threlfall a quartz fibre will stand one-third of a turn for every one-half inch in a fibre $\frac{4}{10000}$ inch in diameter. It is also unaffected by ordinary atmospheric or temperature changes, and has so great a tensile strength that, for the same system, its coëfficient of torsion will be less than that of the finest silk fibre. We are able now to draw these fibres out to any length and to any degree of fineness with great facility. You may wonder how the hooks are placed upon the fibre: by simply platinizing the ends and soldering the hooks to them. When we first established our laboratory at Ardmore, all the suspensions of all our galvanometers on this general type were of silk; now I doubt whether a silk fibre can be found anywhere, all are either quartz or metallic. Some of these fibres have been made and are occasionally used for the most delicate suspensions, so fine that it has been impossible to see them except by the interference colors which are produced; to the eye there is a flash of beautiful iridescence, nothing more. Their tensile strength is very great, over 150,000 pounds to the square inch in the finer sizes. I made mention of the fact that the magnets of the system are threaded upon a quartz rod; there is a reason for this also, which we have

discovered, and which, as far as I know, has not been thought of by others. It is simply this: any wire, during drawing, is put under mechanical strain and forced into a certain condition which will gradually work itself out. The resistance of wires of all kinds is greater immediately after drawing than it will be a little later, speaking, of course, with reference purely to mechanical changes and not to chemical ones. The wire is hardened by drawing and slowly anneals by contact with ordinary atmospheric temperatures. The same is true of glass as is well illustrated by the changes which take place in thermometers after they have first been made, unless the glass used has been kept in the tube form for a great length of time. Good thermometer makers consider it necessary to hold glass for several years before being used, if the thermometers are to be really standard. All this is not true, however, of quartz, and if it were possible to obtain quartz in the right shape or to get it into that shape and work it, we should be able to make thermometers almost absolutely correct and which would remain so. Now, let us again look at the system shown in *Fig. 5*. Here there are two sets of magnets, or, essentially, two magnets, with their poles in opposite directions. Let *Fig. 10* represent, diagramatically, these two magnets opposed to one another but not quite in the same plane. These two magnets are evidently equivalent to another magnet whose plane will be somewhere in the angle θ; let us suppose that it lies in the position indicated by the dotted line; this dotted line will, therefore, lie in the plane of the earth's meridian, assuming for convenience that no other field but that of the earth is operative. If, now, either of the magnets shifts its plane with reference to the other there will be a corresponding shifting of the resultant plane or the *system* will rotate until the *new* plane is in the earth's meridian. We will, therefore, have "drift" again but due to another cause. If we use aluminum or other metal wire the twist produced by the original drawing of the wire will slowly work itself out, perhaps taking months to do so, and we will always be more or less bothered by the consequent drift. Glass is equally bad as metal. Quartz, however, will not alter and is perfect

for this purpose. To prove our hypothesis we took aluminum wire upon which was a system, and in which there was but little drift, and gave the wire a slight twist; drift invariably followed and in the direction which theory would lead us to expect from the direction of twisting.

PROCEEDINGS.

[*Stated meeting, held Tuesday, November 22, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 22, 1892.

Prof. Edwin J. Houston, President, in the chair.

Present, twenty-seven members and visitors.

The minutes of the previous meeting were read and approved.

The Treasurer reported the cash balance in the treasury, and presented bills for printing, which were approved and ordered paid.

Two nominations to membership were referred to the Committee on Admissions. The Committee reported two members elected since last meeting.

Nominations for officers for 1893 being in order, Prof. E. J. Houston was nominated for President for another term, but declined with regret on account of the press of other business. The following nominations were then made and duly seconded:

For *President,*	Mr. Elmer G. Willyoung.
For *Vice-Presidents,*	Prof. Edwin J. Houston, Mr. C. W. Pike.
For *Secretary and Treasurer,*	Prof. L. F. Rondinella.
For *Conservator,*	Dr. Wm. H. Wahl.

(*The election will take place at the December meeting.*)

Mr. E. G. Willyoung read a paper on "Some New Apparatus for the most exact Comparison and Adjustment of Resistance Standards and the Determination of Temperature Coëfficients." The paper was illustrated with some fine examples of the apparatus described, and was referred for publication.

Mr. O. T. Louis presented a communication on "Errors in the Determination of Areas from Measured Diameters." This was illustrated by a diagram and blackboard sketches, and was referred for publication.

Mr. Nelson H. Genung read a paper on "Recent Improvements in the d'Arsonval Galvanometer," illustrated by a fine instrument of the type made by Queen & Co., arranged in working order. Referred for publication.

The meeting then adjourned. L. F. RONDINELLA, *Secretary.*

RECENT IMPROVEMENTS IN D'ARSONVAL GALVANOMETERS.

By Nelson H. Genung.

[*Read at the stated meeting of the Electrical Section, November 22, 1892.*]

To see an elaborate electrical instrument highly lacquered and polished standing in the show-case of some college laboratory is one thing; to see the same or a similar instrument in the working drawings or in a thousand and one pieces on the workman's bench ready for assembling is quite another thing. It is in the latter case only, when one sees here and there a part insignificant in itself but on which may depend the success of the instrument as a whole, that one is brought to realize the necessity of looking after the smallest details in instrument construction. It is certainly difficult for a person unacquainted with the manufacture of fine instruments to fully appreciate the range of electrical and mechanical knowledge which one must possess in order that he may plan the working drawings for a high-grade instrument which shall work satisfactorily when completed, which shall conform strictly to mathematical principles, which shall include in neat and attractive mechanical form all the latest improvements applicable to that particular type of instrument, and which shall, in so far as is possible, conform to standard sizes of material so as to reduce the cost of manufacture to a minimum. It is only by continuous study and practice that one acquires satisfactorily the knowledge necessary for such an undertaking.

A thorough and systematic study of the Deprez-d'Arsonval type of galvanometer has recently been made by the writer with the ultimate intention of throwing this class of instruments into a variety of forms for both the college and commercial trades. The paper presented to you this evening will include, among other things, an historical sketch of the Deprez-d'Arsonval galvanometer, a little mathematical reasoning concerning aperiodic galvanometers of this type,

a brief review of the most noteworthy improvements recently made in this class of instruments, and a detailed description of a d'Arsonval galvanometer, which, in the course of its design, has been thoroughly criticised from both a theoretical and mechanical standpoint, and which, although not yet fully completed, has yielded extremely satisfactory results.

A galvanometer is an elctrical measuring instrument in which use is made of the electro-magnetic properties of currents. A coil of wire traversed by an electric current sets up a magnetic field of its own, the strength of which at any point depends on the strength of the current flowing. Suppose this coil to be mounted vertically, and with its plane parallel to the magnetic meridian, a magnetic needle suspended in its axis will, when no current is flowing, assume a direction parallel to the horizontal component of the earth's field, but on introducing a current the needle will be deflected from this its zero position, through some definite angle depending on the relative strengths of the two magnetic fields involved. Thus we see that by this method the measurement of current is reduced to a measurement of the strength of field produced by it.

Numerous modifications may be introduced so that for a given strength of current the angular deflection of the needle may be materially increased. This increase in the sensibility, as it is called, has been brought about in several ways, such as decreasing the torsional control of the suspension fibre, reducing the moment of inertia of the movable parts, increasing the length of wire acting on the needle, reducing the mean distance of the coil from the needle and decreasing the strength of the earth's field in the vicinity of the needle by means of a control magnet. A discussion of these points being beyond the range of this paper will be omitted. Brief reference, however, will be made to the last one mentioned as it furnishes a stepping-stone to what is to follow concerning d'Arsonval galvanometers.

The extreme annoyance experienced in attempting to use a galvanometer of the above-described type, made sensitive by neutralizing the earth's effect on the needle by means of a control magnet is well-known. The original or earth's field

and the temporary field set up by the control magnet being nearly equal and opposite in direction destroy, almost completely, each other's effect on the needle. A slight variation in strength or direction of either of these fields or the introduction of a third field, however weak it may be, is often sufficient to cause the needle to turn completely around. This subject received full and thorough treatment in a paper read by Mr. Elmer G. Willyoung,* at our last meeting.

It was mainly with the idea of obviating this difficulty that Marcel Deprez,† about the year 1880, introduced into galvanometer construction what has since proved an important and desirable modification. He placed the galvanometer needle between the poles of a powerful horse-

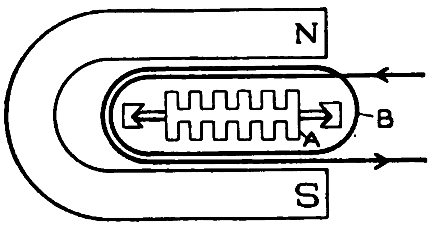


FIG. 1.

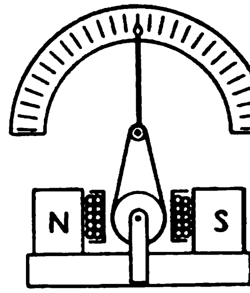


FIG. 2.

shoe magnet, thus freeing it from all local magnetic disturbances and giving it a short period of oscillation, but at the same time causing it to lose almost entirely its sensibility. He afterwards substituted a soft iron laminated needle which when placed in position became strongly polarized by induction. *Fig. 1* shows the general arrangement adopted by him, and known under the name "*galvanomètre à arête de poisson*," galvanometer of herring-bone work. The soft iron needle *A* is mounted within the galvanometer coil *B*, and both are surrounded by the horseshoe magnet *N S*.

* "A New Standard Ballistic Galvanometer with Variable Sensibility and without 'Drift,'" by Mr. Elmer G. Willyoung, New York *Electrical Engineer*, November 16, 1892.

† "On Electrical Measuring Instruments: Ammeters and Voltmeters," by Marcel Deprez, *La Lumière Électrique*, April 30, and November 5, 1881.

The range of movement of the needle is, however, very small and the deflections far from being proportional to the currents measured.

A multiplying device, similar to that shown in *Fig. 2*, was added a little later, which obviated these difficulties to a considerable extent. The scale was at that time usually divided into degrees, thus necessitating the use of a table of values or a calibration curve.

The next step was to retain this powerful control magnet and astaticise the movable system. M. d'Arsonval* concluded that so long as the moving parts contained any magnetic material this would be utterly impossible, the directing force being always very great as compared with the deflecting force. In order to accomplish this he aimed at making the directing forces very weak and the deflecting force very

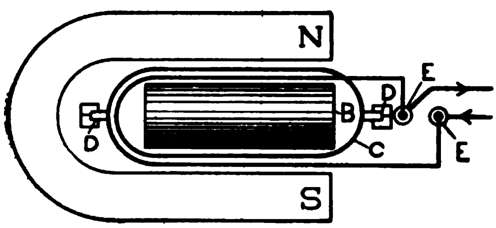


Fig. 3.

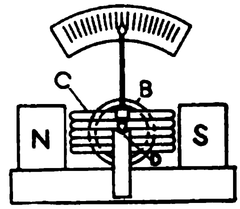


Fig. 4.

powerful, and succeeded by fixing the soft iron needle and making movable the current coil of the Deprez instrument. The general arrangement remaining the same, the number of parts was not materially increased. The control being non-magnetic could be made as weak as might be desired, the deflecting force remaining practically the same. *Figs. 3* and *4* show d'Arsonval's arrangement in which *N S* represents the permanent horseshoe magnet, the poles of which are thirty millimetres apart; *B*, the fixed soft iron tube or needle, about twenty-five millimetres outside diameter, which extends nearly the whole length of the magnet; *C*, the coil mounted on knife-edges *D D* and provided with mercury contacts *E E*, coinciding with the axis of rotation.

* "A new Deprez-d'Arsonval Astatic Galvanometer," by M. Deprez, *La Lumière Électrique*, September 7, 1881.

Almost any desired sensibility may be attained by properly adjusting the centre of gravity of the movable system.

A few years later this galvanometer was constructed as shown in *Fig. 5*, by M. Carpentier, in which form it has practically remained to the present day.

Lord Kelvin probably first made use of the above principle in the construction of his siphon recorder used as a receiving instrument in submarine telegraphy. M. d'Arsonval* says regarding his own application of this principle: "This apparatus rests upon the same principle as does the siphon recorder of Wm. Thomson. It is seen that I have

FIG. 5.

arrived at the same combination, starting from another point of view and that I have also transformed into a *galvanometer*, an apparatus which up to then had been used only as a telegraph receiver." In the same article he continues, "I have given to this apparatus the name of *Deprez-d'Arsonval galvanometer* in order to recall its origin."

A successful attempt was made in 1884 by Deprez† to

* "Aperiodic Galvanometers of Great Sensibility," by M. d'Arsonval, extract *de la Revue Internationale de l'Électricité et de ses Applications*, April, 1886.

† "On a Galvanometer in which the Indications are Proportional to the Current Strength," by M. Deprez, *La Lumière Électrique*, December 13, 1884.

construct a d'Arsonval galvanometer giving proportional indications. In an article published by him at about that time he says, "The deflections of the needle are exactly proportional to the intensities of the current even when deflected 120°." Two soft iron pole pieces circularly cut out were employed. These pole pieces *B B*, see *Fig. 6*, and the soft iron cylindrical core *C* were rigidly attached to the magnet. Within the annular space occupied by the coil *A*, the magnetic field is strong and uniform and the lines of force are normal to the polar and core surfaces. The coil thus always moves through a uniform magnetic field, cutting the lines of force everywhere normally.

Another arrangement of pole pieces,* see *Fig. 7*, has been proposed which is capable of giving to the coil a much

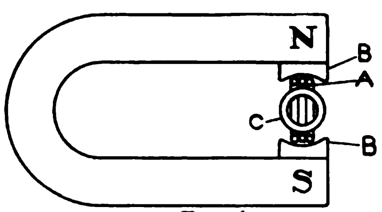


FIG. 6.

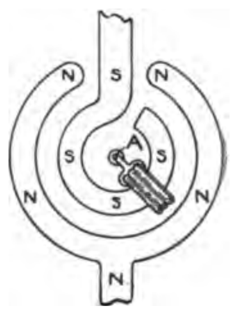


FIG. 7.

wider range of movement in a perfectly uniform field. This arrangement has, however, one or two disadvantages worth mentioning. The coil being pivoted at the centre *A*, has a comparatively large moment of inertia, which prevents it from coming to rest so quickly as it otherwise would. The amount of "dead" wire is also very great. By "dead" wire is meant all that portion of the coil not so disposed with reference to the field as to assist properly in the deflection, the "active" wire being that portion which moves properly in the magnetic field. This point is very satisfactorily illustrated in *Fig. 8*. The portions *L N* and *M R* in all three of the coils are so disposed, with reference to the axis of rotation and to the lines of force, as to assist in the deflection.

* See *La Lumière Électrique*, March 24, 1888.

The wire making up these portions is called the "active" wire of the coils. The wire making up the portions *L M* and *N R* takes no active part in the deflection, and is, in consequence, called the "dead" wire.

In an instrument to be used merely as a current detector, the deflections being usually very small, it is desirable to concentrate the field as much as possible by employing convex or conical pole pieces, so as to give to the coil a maximum deflecting force. Square or concave pole pieces give a weaker field for the coil at the start, but as the deflections increase the active portions of the coil pass into a gradually increasing strength of field, which makes up for

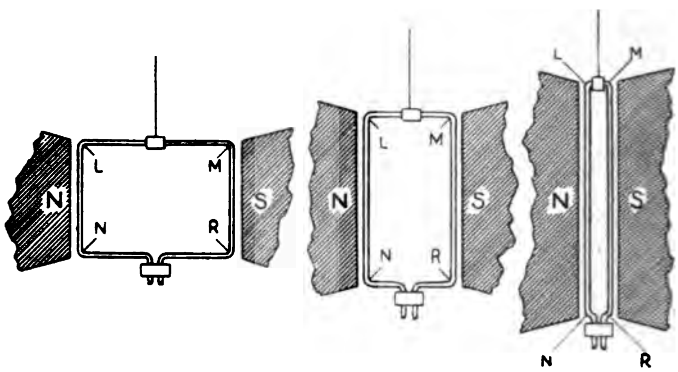


FIG. 8.

the loss in deflecting moment due to the shortening of the arm of the couple.

The leakage of the lines of force around the space occupied by the coil is likely to be much greater in horseshoe than in circular magnets, see *Figs. 9* and *10*. By adopting an arrangement similar to that shown in *Fig. 3*, nearly all the lines are utilized, but the great length necessarily given to the coil in order to capture the comparatively small number of lines near the bend in the magnet, is not a desirable feature in instrument construction. The iron core, however, doubtless tends to distribute the lines somewhat uniformly throughout its entire length. The increase in sensibility by this means is more than counter-balanced by the additional moment of inertia necessarily given to the

coil, which shows that the lines might better be concentrated at or near the poles proper, circular magnets being employed to avoid any appreciable loss due to leakage.

A novel arrangement of coil and magnets has recently been adopted by M. Gaiffe,* of Paris, in milliampèremeter construction. He has done away with the soft iron core and makes the deflections proportional to the intensities by employing two magnets of cylindrical form, as shown in *Fig. 11*. The coil in this arrangement contains a large amount of "dead" wire, being necessarily quite broad, and has a considerable moment of inertia as well. The range of movement, also, is not materially increased.

Turning our attention now to the movable system we find that when the coil is deflected from its position of

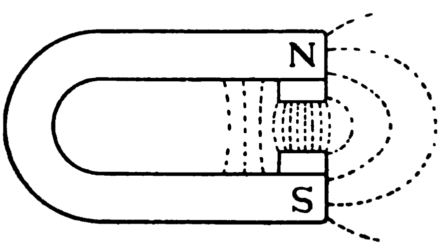


FIG. 9.

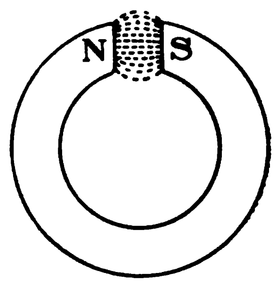


FIG. 10.

equilibrium there is a torsional couple due to the suspension which tends to bring it back. This is the only directive force brought to bear on the system. The moment of this couple is a function of the angle of deflection, and may be made almost anything desired by varying the length and cross-section of the suspension wire. Aside from this directive force, there are various retardative forces at work when the coil is in motion, due to the reaction of induced currents, friction with the air, and the like, which tend to bring the system to rest. These forces are functions of the angular velocity of the system.

In the movement of the coil of a galvanometer of this type we have an example of the rotation of a solid about an

* *La Lumière Électrique*, September 3, 1892.

axis in which case the product of the angular acceleration by the moment of inertia of the movable system is equal to the sums of the moments due to the directive and retardative forces. The differential equation for the movement of the coil thus becomes

$$\Sigma m r^2 \frac{d^2 \theta}{d t^2} + A \frac{d \theta}{d t} + B \theta = O$$

in which θ represents the angular deflection in time t, $\Sigma m r^2$ the moment of inertia of the coil, A a constant for the retardative forces and B a constant for the torsional couple.

Imagine now the retardative forces to become negligable, the coil, when set in motion, acquires the same velocity every time it passes its position of equilibrium and makes a series of perfectly identical oscillations. It is thus said to

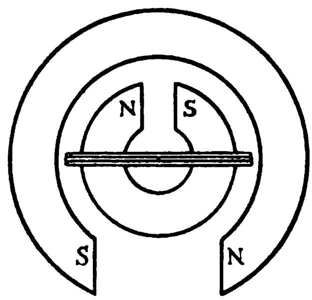


FIG. 11.

have a *periodic* movement. The time of oscillation of the coil may be greatly increased, either by increasing its moment of inertia or by decreasing the directive moment due to the suspensions, the oscillations still remaining isochronous.

If, now, B is left constant and A made to increase gradually, the period becomes greater and greater as the logarithmic decrement increases. Finally, A having attained a considerable value, due to self-induction in this case, the coil on being drawn to one side and released, returns to its position of equilibrium, moving rapidly at first then more and more slowly, finally coming to rest. Infinite time is required theoretically for accomplishing this; practically, however, the zero point is reached in the course of a few seconds.

Suppose the only damping effect on the needle to be that due to induction ; A is then equal to

$$\frac{F^2 S^2 n^2}{R}$$

where F represents the strength of the field ; S, the area of the coil ; n, the number of turns composing it, and R, the total resistance in circuit. Since the value of A depends on the total resistance R as the only variable, the field remaining constant, it should become zero when R reaches infinity; that is, when the coil is on open circuit. As a matter of fact, however, A does not become zero quite since the damping, due to friction with air, is not wholly negligable. By decreasing R the value of A increases and the coil finally assumes an *aperiodic* movement. A solid rotating about an axis is said to have an "aperiodic" movement when it takes up its new position immediately and without oscillation. By setting a d'Arsonval galvanometer coil of low resistance to oscillating on open circuit between the poles of a powerful horseshoe magnet, the transition from the periodic to the aperiodic movement is easily followed, as the circuit is closed through a high external resistance which is gradually reduced until the coil is short-circuited.

Time will not be taken to go more deeply into the theory of this instrument, as there are many points of more interest and greater importance which should be taken up. The theory of aperiodic galvanometers of the Deprez-d'Arsonval type has been thoroughly reviewed and experimentally verified by M. Ledeboer,* to whose paper the reader is referred in case he desires to go more deeply into the theoretical reasoning.

As early as 1881, Deprez† speaks of short-circuiting the coil for the purpose of damping the oscillations. The only resistance in circuit then being that due to the coil, the

* "Theory of Aperiodic Galvanometers," by M. Ledeboer, *Journal de Physique*, second series, vol. vi, p. 53, 1886. Also *La Lumière Électrique*, June 26, 1886.

† "New Deprez-d'Arsonval Astatic Galvanometer," by M. Deprez, *La Lumière Électrique*, September 7, 1881.

currents induced are sufficient to bring the needle slowly to rest. Closing the article, Deprez says: "This characteristic makes the instrument applicable to the measurement of resistances."

In the well-known Weston instrument, constructed on the Deprez-d'Arsonval plan, the coil is wound on a copper frame which serves the purpose of damping very effectively. This frame acts the same as would a single turn of heavy wire dead short-circuited on itself, and moving as it does in a powerful magnetic field the inductive effect is sufficient to make the instrument practically "dead beat."

Weston has also proposed the electrolytic deposition of a layer of copper over the entire surface of the coil, which shall serve the same purpose. Ayrton and Mather* have encased the coil of their recently constructed d'Arsonval in a silver tube, which serves both as a damper and as a protection to the coil. The coil is rigidly attached to this tube, which forms a part of the movable system.

Numerous other modifications of this method for damping have been proposed, such as short-circuiting any number of turns on the coil, adding a separate coil which shall be short-circuited, providing a copper disc which shall rotate properly between the poles of a powerful magnet, and the like, all of which are amply sufficient for the purpose.

Apparently no particular attention was paid to the best form of coil to be used in d'Arsonval galvanometers at the time when the best shape of pole pieces was being so thoroughly studied. In a paper on galvanometers, by Messrs. Ayrton, Mather and Sumpner,† the conclusion is drawn that the most sensitive galvanometer attainable is one of the d'Arsonval type suitably modified. For accomplishing this they say that the pole pieces should be very close together, the coil very small and no stationary iron core employed. The sensitiveness could be further increased by employing electro-magnets instead of permanent ones.

* "The Ayrton-Mather-d'Arsonval Galvanometer," *London Electrician*, July 29, 1892.

† "On Galvanometers," a paper read before the Physical Society, *London Electrician*, February 7, 1890.

The coil should also be long and narrow and the controlling force reduced to a minimum whenever great sensibility is desired.

Mr. Mather,* a little later, presented a paper before the Physical Society, in which he exhibited the results of a thorough study on the best section of coil perpendicular to the axis of rotation. Quoting from this article: "Since for a constant period the controlling moment at unit angle must be proportional to the moment of inertia, the problem is to determine the shape of the section so that the ratio of the deflecting moment to the moment of inertia may be a maximum." The six sections shown in *Fig. 12* are taken from the above-quoted article. In *A* the deflecting moment per unit moment of inertia is 1·02, in *B* it is ·80, in *C* ·97, in

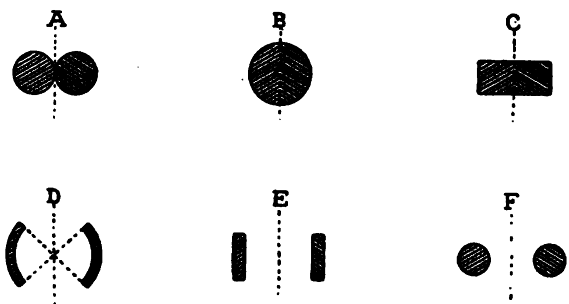


FIG. 12.

D ·44, in *E* ·47 and in *F* ·40. Coil *A* is, as may be seen, more efficient than any of the others. These calculations are based on coils in which the length is great in proportion to the cross section.

As to the kind of wire to be used in these coils nothing in particular need be said. Copper is usually employed the same as in most galvanometers of the various other types. If, however, the accuracy of the instrument depends to any considerable extent on the permanency of its resistance, it is better to employ a wire, having a much lower temperature coëfficient although its resistance may be considerably increased.

As has already been pointed out, the coil of the d'Arsonval

* London *Electrician*, April 11, 1890.

galvanometer in its earliest form rested on knife-edge supports, and was provided with mercury cup connections and gravity control. In the Carpentier arrangement the coil was mounted on a vertical axis. The suspensions in this latter case being of wire served the threefold purpose of suspension, conductor and control. A little later, long spiral springs were employed as conductors and control the coil being supported by means of a cocoon fibre.*

Suspension wires in a variety of sizes, shapes and materials have been employed at various times. Silver, platinum, silver-platinum, platinoid, German silver and phosphor-bronze are all materials for this purpose, the phosphor-bronze being on the whole the best, as it is little likely to corrode and is the least likely to take a permanent "set," thereby causing a slight change in the "zero point." The variation in sensibility due to the "time change," is also very small in the case of phosphor-bronze suspensions.

Flat strips possess a much smaller control than do round specimens of the same material having the same area of cross section. A suspension having a rectangular cross section the breadth of which is five to ten times the thickness has been recommended as the best form to adopt whenever a minimum control is desired. All other conditions remaining the same, Prof. Ayrton concludes that a flat strip suspension will give a deflection five times as great as will a round suspension of the same cross section. The liability to error due to a shifting of the "zero point," the result of a slight permanent "set," is much reduced by employing the strip. The radiation surface is at the same time considerably increased, this being often a matter of great importance in cases where very fine suspensions are necessary.

For commercial work the coil is usually supported in jewel bearings, springs serving for both control and conductors. In the well-known Weston instrument and in the milliampèremeters recently placed on the market by Mr. Gaiffe, flat spiral springs made from phosphor-bronze strip have been adopted.

Electrician, Februa*ique*, 1887, p. 530.

In Prof. Ayrton's article, to which reference has previously been made, is described a form of d'Arsonval galvanometer having a coil of platinoid wire, the cross section of which is the same as that shown in *A*, *Fig. 12*, the iron core being necessarily absent. In this form the coil, mountings and frame work supporting the same are bodily removable from the instrument. A d'Arsonval galvanometer, designed by Messrs. Ayrton and Mather, was exhibited for the first time at a recent meeting of the Physical Society. This instrument, as you can readily see from the one before you, employs the narrow coil mounted in a silver tube, which forms a part of the movable system, and is suspended by a flattened phosphor-bronze wire. A button presses against the side of the silver tube by means of a spring which preserves the system from injury, when transportation is desired. The magnet is of one piece of metal, and has square pole faces. The movable system is mounted in a brass tube which may be removed, and another tube containing another coil slipped in place. The mirror cage and clamping device are both attached to this tube. The total height of the instrument is 6 inches, length of suspension tube $5\frac{3}{4}$ inches, outside diameter of magnet 4 inches, length of coil 2 inches, and diameter of silver tube $\frac{1}{8}$ inch. The coil has a period of about one and one-fourth seconds and is damped by the silver tube sufficiently to bring it to rest with about five complete oscillations.

We will now turn our attention to the new Queen d'Arsonval galvanometer, this being its first appearance outside of their factory and electrical laboratory. *Fig. 13* shows the assembled instrument. All the parts are of rigid construction, and the instrument, as a whole, while it presents a pleasing appearance, presents a rugged workshop-like appearance as well.

The magnet has an outside diameter of four and one-half inches, and is built up of thirty-five discs one-tenth of an inch thick held together by means of three bolts. These discs are cut from the best sheet steel obtainable and are hardened glass hard. After having been thoroughly magnetized great care is exercised not to subject them

to any rough usage. The magnet rests on a sheet of hard rubber *A*, *Fig. 14*, which insulates it completely from the metal tripod base. The pole faces *BB* are concaved, thus tending towards uniform deflections. At the same time the corners are slightly rounded, thus avoiding too great a leakage around the coil. The suspension tube *C*,

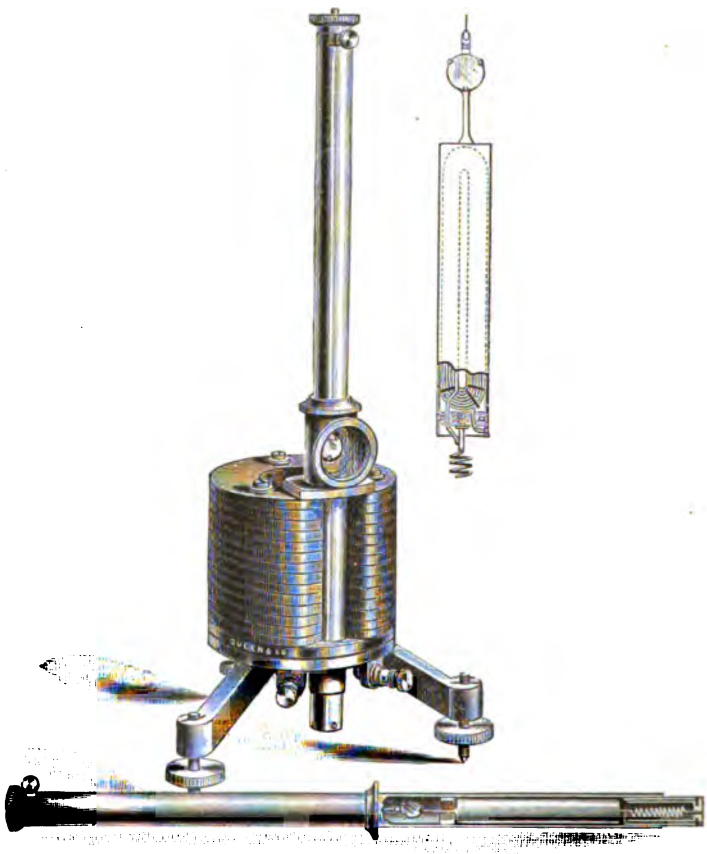
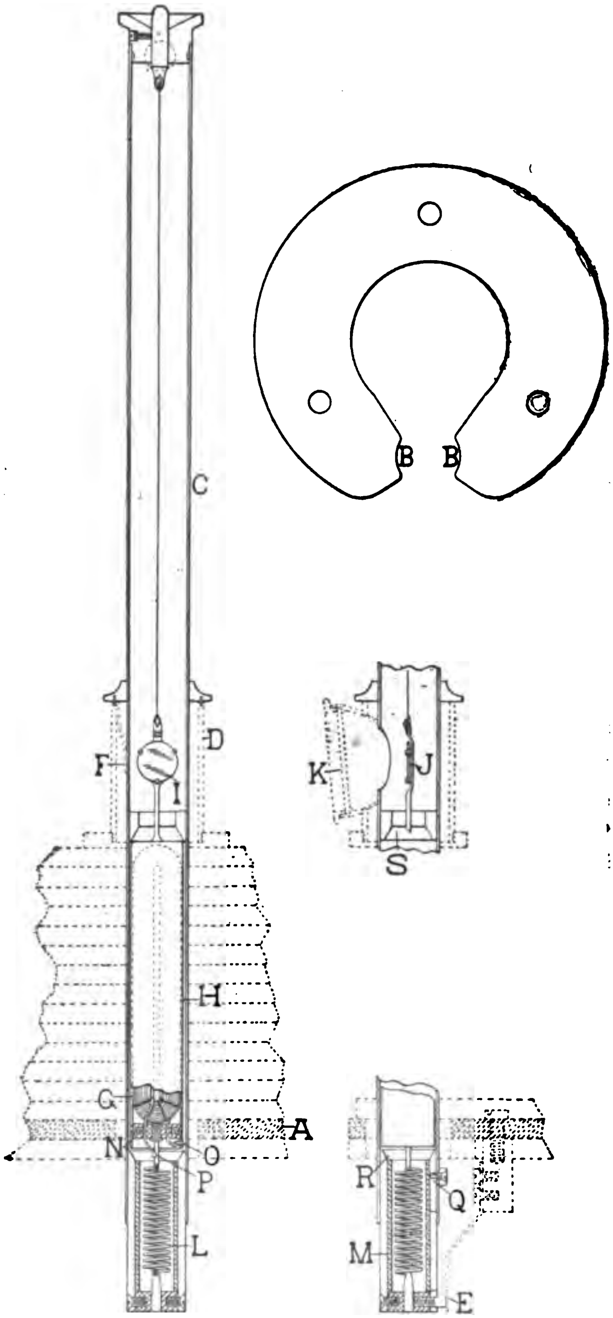


FIG. 13.

sixteen inches long over all, slides freely between the poles, which, together with the mirror cage *D* attached to them, hold it rigidly in position. This tube containing the entire system may be slipped out without the necessity of loosening a single screw and another tube put in place. Connections are made automatically by means of sliding contacts



B
FIG. 12.

at E and F. The coil G fills the aluminum tube H, to which it is rigidly attached. The space within this tube allotted to the coil is $3\frac{1}{2}$ inches long by $\frac{9}{16}$ inch in diameter. The coil itself has a cross section represented by two tangential circles, as shown in *Fig. 8*, this being the most approved shape. It may be wound either of copper, or of platinoid wire as may be desired. To the top of the aluminum tube is attached the mirror I, held in place by a three-armed aluminum clip, thus avoiding the use of wax. The silvered surface of this mirror lies in the axis of rotation as shown at J, thus eliminating one source of error usually overlooked in galvanometer construction. The glass window K of the mirror cage is tilted, as shown, so as to avoid reflection of the scale from its surface into the telescope. The suspensions may be of any desired material. Flattened phosphor-bronze wire is, however, usually employed, a long spiral spring L, forming the lower connection. The portion of the tube surrounding the spiral has a hard rubber lining M, which avoids all possibility of short-circuiting. The terminals of the coil pass through the hard rubber base N, of the aluminum tube, one being soldered at O, to a copper plug riveted into the side of the aluminum tube, and the other at P, to the projection to which the spiral spring is attached. The lower end of this spiral is electrically connected, by means of the platinized spring contact E, to one binding post. The other binding post is reached through the aluminum tube, the upper suspension, the suspension tube, the platinized contact at F, the mirror cage D, and the magnets. The lower end of the suspension tube makes sliding contact with the tube proper, its range of movement being limited by the slot and pin at Q. As a means for clamping the system, the upper edge of this sliding portion is reamed out, as shown in the figure at R, and just above the aluminum tube is fastened a collar S, similarly shaped. When the lower end of the tube is shoved up, the coil is not only clamped but lifted slightly as well, thus entirely relieving the suspension wire of all strain. By this means the coil is held perfectly rigid during transporta

tion without the least fear of injury to any part of the system.

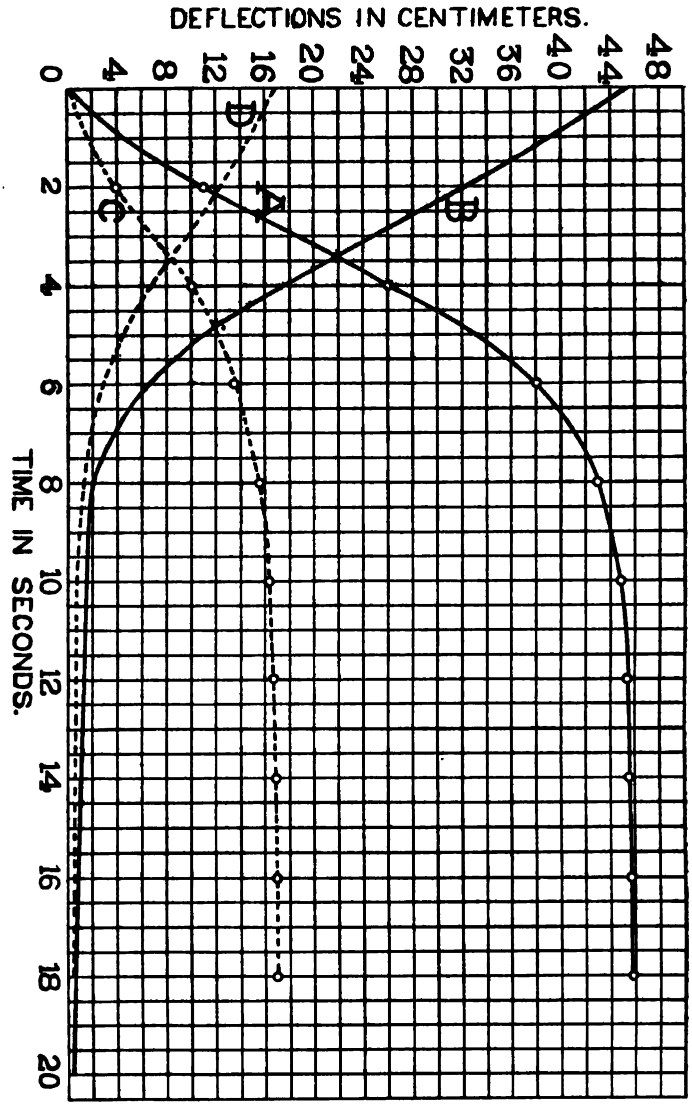


FIG. 15.

Starting the coil of this instrument from a position of rest, its position was noted every two seconds until it had again come completely to rest. The curves, *Fig. 15*, are

intended to represent this movement. Curve *A* was obtained by closing the circuit through a resistance sufficient to give about forty-six centimetres deflection. Curve *B* was obtained

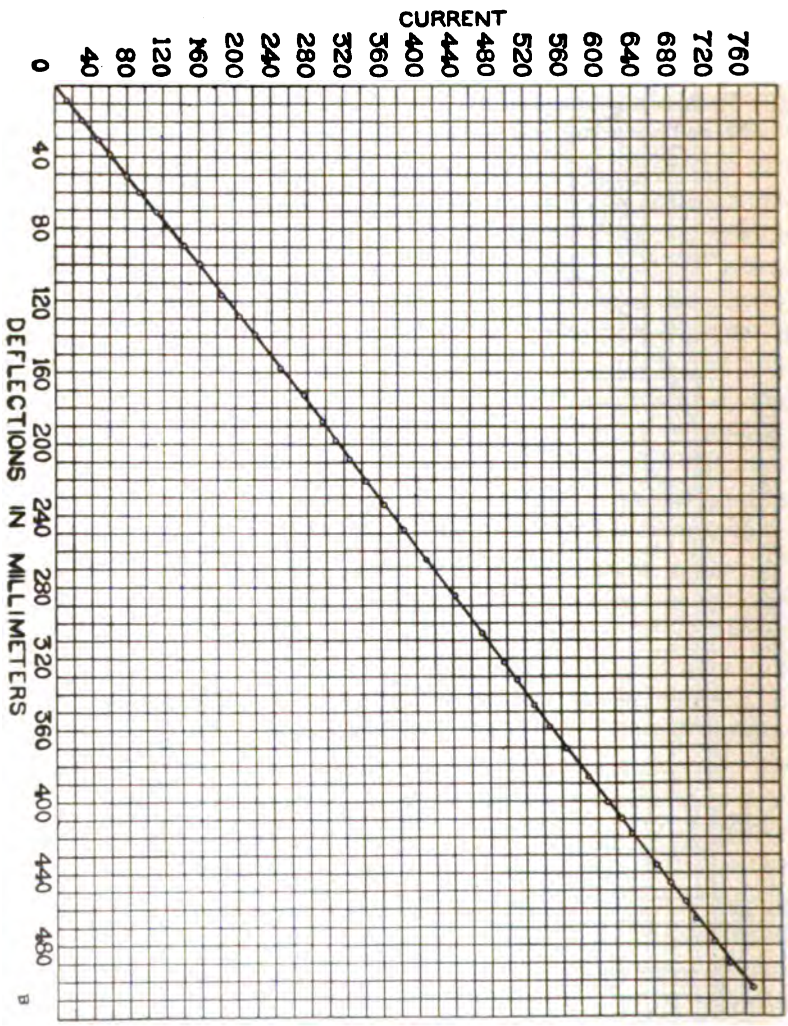


FIG. 16.

by breaking the circuit thus allowing the needle to return to zero. Curves *C* and *D* were obtained in a similar manner, the deflection being only about sixteen centimetres. From

these curves it is easily seen that the movement of the coil is absolutely aperiodic; that is, it moves directly to its position of rest, approaching it more and more slowly, without showing the least sign of an oscillatory movement.

The curve, *Fig. 16*, is practically a calibration curve of the instrument. Abscissæ show the deflections in millimetres on a scale placed at a distance of one metre and the ordinates the corresponding currents. To obtain the values of the currents in fractions of an ampère multiply the ordinate readings by ·00000001. This curve, practically the first one yet taken from the instrument, is very nearly a straight line curve which shows that the readings on a straight scale are very nearly proportional to the currents producing them.

The coil employed in obtaining the above data was wound with No. 36 copper wire, single silk insulation, having 694 turns and a resistance of 178 ohms. Its size and shape were as previously mentioned. The suspension was of platinum silver wire, 0·0014 inch round, and the spiral spring at the bottom was of the same material 0·0019 round. Phosphor-bronze strip has been delayed in reaching us in time for the paper. A small amount, however, has just been received and given the barest trial. The width of this strip is 0·006 inch and the thickness 0·0005 inch. The round platinum silver suspension and spring being replaced by this phosphor-bronze strip made the instrument much more sensitive, one volt pressure through 200 megohms now giving a deflection of one millimetre on a scale one metre distant. Under these conditions about fifty-five seconds are required for the coil to deflect and about forty for it to return to zero, which shows that a perfect aperiodic movement has been attained. The damping effect can easily be modified, so that this extremely slow movement will by no means appear as an objectionable feature to the instrument.

Extra tubes containing coils and suspensions of any desired material, resistance, etc., are supplied with the instrument. Tubes containing coils intended for ballistic purposes are also supplied. These latter are free from damping due to induction, a short-circuit key being amply sufficient to stop all movement of the system whenever desired.

The work on d'Arsonval galvanometers is being continued with the intention of getting out an instrument of this type which shall have an extremely high sensibility, rivalling that of the Thomson square pattern galvanometer. The results thus far are very encouraging, and within a few months you may hope to see this instrument in tangible form.

ERRORS IN THE DETERMINATION OF AREAS FROM MEASURED DIAMETERS.

By O. T. Louis.

[*Read at the meeting of the Electrical Section, held November 22, 1892.*]

In scientific determinations made at the present day, the accuracy of the determination is the paramount question. The problem is not to measure a length to ·01 millimetre or a resistance to ·0001 of an ohm, but to determine a length or a resistance with an accuracy of ·01 or ·001 of one per cent. Little improvements often increase accuracy to a marked extent. To one of these little wrinkles, I would call attention to-night.

In some recent work in the measurement of conductivity at Queen's Laboratory at Ardmore, I had occasion to study the methods of determining the cross section of the specimens in question. The area could be determined in two ways: by calculation from the volume obtained by the determination of the mass and specific gravity and by calculation from a directly measured diameter. The latter method is of course the simpler and where a good chemical balance is absent the only one to be employed. To call attention to a few points to be observed in this latter method is the object of this paper.

Let δ equal the true diameter of any geometrical cross section, the area of which is to be determined.

Then $k\,\delta^2$ can be taken as the area of that cross section, k being a constant varying from

$$1 \text{ to } \frac{\pi}{4}$$

for all figures from the square to the circle.

In measuring a diameter by micrometer calipers two things may occur: the diameter may be measured too large by slightly twisting the calipers or by the presence of bends, or made too small by crushing the surfaces measured. Let the error thus made be called a. Then the measured diameter is

$$(\delta \pm a) \tag{1}$$

and the area becomes

$$k\,(\delta \pm a)^2 \tag{2}$$

the true area being

$$k\,\delta^2 \tag{3}$$

and, therefore, the error is

$$k\,\delta^2 - k\,(\delta \pm a)^2 \tag{4}$$

and the percentage of error is

$$\frac{k\,\delta^2 - k\,(\delta \pm a)^2}{k\,\delta^2} \tag{5}$$

Simplifying expression (5) we obtain

$$\frac{\delta^2 - (\delta \pm a)^2}{\delta^2}$$

$$\left.\begin{aligned} &\therefore \quad \frac{\delta^2 - \delta^2 - 2\,a\,\delta - a^2}{\delta^2} \\ &\text{and} \\ &\qquad \frac{\delta^2 - \delta^2 + 2\,a\,\delta - a^2}{\delta^2} \end{aligned}\right\} \tag{6}$$

or

$$\frac{2\,a\,\delta + a^2}{\delta^2} \tag{7}$$

$$\frac{2\,a\,\delta - a^2}{\delta^2} \tag{8}$$

From expression (7) will be seen that when the diameter is measured too large, then the percentage of error in measuring the area is

$$\frac{2\,a\,\delta + a^2}{\delta^2} \tag{7}$$

and the percentage of error when the diameter is measured too small

$$\frac{2\,a\,\delta - a^2}{\delta^2} \tag{8}$$

A comparison and discussion of expressions (7) and (8) bring out several interesting points.

The percentage of error in measuring the diameter is

$$\frac{a}{\delta}$$

in measuring the area the maximum error is

$$\frac{2\,a\,\delta + a^2}{\delta^2}$$

the ratio of the two errors is, therefore,

$$\frac{2\,a\,\delta + a^2}{\delta^2} \times \frac{\delta}{a} = \frac{2\,\delta + a}{\delta} \tag{10}$$

Expression (10) may be given the form

$$2 + \frac{a}{\delta} \tag{11}$$

Expression (11) shows us two interesting facts. First, when the diameter is measured greater than it really is then the minimum ratio of the error of area to diâmeter is 2, and the maximum ratio is 3. a is generally small compared with δ. This brings out the fact that the common opinion that the error in the area is equal to the square of the error in the diameter is erroneous. Expression (11) shows that the actual error is never far from double the error of the diameter.

Hitherto we have been considering the case when the measured diameter is greater than the actual. Let us consider expression (8) in which the measured diameter (due say to crushing) is less than the actual diameter. In this case we have the percentage of error as

$$\frac{2\,a\,\delta - a^2}{\delta^2}$$

If we divide this by

$$\frac{a}{\delta}$$

we obtain as before the ratio of the error of area to the error of the diameter.

$$\frac{2\,a\,\delta - a^2}{\delta^2} \times \frac{\delta}{a} = \frac{2\,\delta - a}{\delta} = 2 - \frac{a}{\delta} \qquad (12)$$

From expression (12) we see, as before, that the ratio is not far from 2, but is always less than 2.

A comparison of expressions (7) and (8) will bring out an interesting fact. From (7) we have

$$\frac{2\,a\,\delta + a^2}{\delta^2}$$

from (8) we have

$$\frac{2\,a\,\delta - a^2}{\delta^2}$$

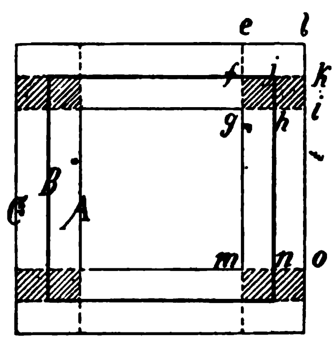
the difference is therefore

$$\frac{2\,a^2}{d^2} \qquad (13)$$

In other words, admitting the same error, we gain

$$\frac{2\,a^2}{d^2}$$

by crushing the wire by an amount a, to having the calipers too loose by the same amount a.



The same thing can be shown more clearly graphically. Let us take the special case of a square, as that permits of simpler demonstration. Three squares are shown, *A B*

C; B is the correct area we desire to measure; C is the measured area when the calipers are too loose; A when the calipers crush the surface to be measured. The diameter of C is $B + a$. Of A is $B - a$. The errors in measuring the areas are the bands between A and B and between B and C. An inspection of the diagram shows that the band $g\,h\,m\,n$ is balanced by the band $h\,n\,o\,i$; the corner $f\,j\,h\,g$ by $j\,k\,h\,i$: but the part $e\,l\,f\,k$ is unbalanced. Similarly for each corner we have a part equal to $e\,l\,f\,k$; therefore, the total area between B and C exceeds the total area between A and B by $4\,e\,l\,f\,k$. But $e\,f\,l\,k$ has the dimensions $\frac{1}{2}\,a \times a$ therefore

$$4\,e\,l\,f\,k = 4\,(\tfrac{1}{2}\,a \times a) = 2\,a^2$$

or the error in measuring the area as C is $2\,a^2$ greater than in measuring it as A; the error percentage gained being

$$\frac{2\,a^2}{d^2}$$

as shown above. Summing up the foregoing it follows that it is always an advantage to screw up the calipers quite tightly as even if the surface is slightly crushed something

$$\left(\frac{2\,a}{d^2}\right)$$

is gained over having the calipers too loose by the same amount a. This rule I have found especially advantageous to use when measuring the conductivity or specific resistance of wire. The surfaces to be measured are in this case generally of sufficiently hard material to prevent any serious crushing by screwing up the calipers tightly. On the other hand, there is a strong probability that if this is not done the kinks and bends which will exist, no matter how carefully the wire be straightened, will increase the apparent diameter. The usual precautions should of course be observed; *e.g.*, the determination of the mean diameter by reading along the whole length of the specimen under examination, test of the zero, etc. By observing these precautions the probable error can be reduced so as not to exceed the errors made in the measurement of the resistance.

ARDMORE, Pa, November 22, 1892.

PROCEEDINGS.

[*Stated meeting, held Tuesday, December 27, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 27, 1892.

Mr. Elmer G. Willyoung, President, in the chair.

Present, sixteen members and visitors.

The minutes of the previous meeting were read and approved.

Two nominations to membership were referred to the Committee on Admissions. The committee reported two elections since last meeting.

The following were elected officers for 1893:

President—Mr. Elmer G. Willyoung.
Vice-Presidents—Prof. Edwin J. Houston and Mr. C. W. Pike.
Secretary and Treasurer—Prof. L. F. Rondinella.
Conservator—Dr. Wm. H. Wahl.

Mr. Edwin F. Northrup read a paper on "Some Principles that must be Observed in the Construction of a good Closed-circuit Battery and some new Portable Dry Cells in which they are Applied." (First paper.) Referred for publication.

The chair called attention to the desirability of full discussion upon papers, and the importance of members hearing papers when read or receiving an abstract beforehand, if possible.

It was moved and carried that the Committee on Papers be authorized to send out abstracts of forthcoming communications with the meeting notices, whenever possible.

Adjourned. L. F. RONDINELA, *Secretary.*

SOME NEW APPARATUS FOR THE MOST EXACT COMPARISON AND ADJUSTMENT OF RESISTANCE STANDARDS AND THE DETERMINATION OF TEMPERATURE COËFFICIENTS.

BY ELMER G. WILLYOUNG.

[*Read at the stated meeting, held November 22, 1892.*]

A little over a year ago I had the honor to present to the notice of the Section some general considerations with reference to the manufacture and adjustment of standard resistances.* During the course of the paper which I then read I exhibited and explained the operation of, to the Section, a piece of apparatus originally suggested to me by Prof. H. S. Carhart, of Michigan University,† and later modified by myself and intended for the very exact comparison and adjustment of standards and the determination of their temperature coëfficients. This apparatus was then and still is being used by Messrs. Queen & Co. as part of their equipment for the commercial doing of this work. This piece of apparatus I have not here to-night, but will sketch it upon the board later in order to bring its details clearly before us. I expressed myself, at that time, as believing it to be perfectly simple and easy to quickly adjust any single standard of resistance by the aid of this apparatus with a certain accuracy of $\frac{1}{100}$ per cent. Since the reading of that paper this method and apparatus have been in constant daily use in our laboratory, and my belief is its convenience and accuracy has been confirmed and strengthened. In the use of the apparatus we have, I

* "Resistance Standards: their Manufacture and Adjustment," *Journal of the Franklin Institute*, April, 1892.

† The first apparatus, made according to Prof. Carhart's design, was made by me either in 1887 or 1888, while I was still a student at the University. It is still in the laboratory there, and in constant use, and is, I am told, as good as ever.

think, at one time or another, been obliged to note every weak point in its theory or construction, and to provide such temporary means as might be obtainable for getting around difficulties as they arose. On a basis of an experience thus obtained I have recently designed and built an improved form of this apparatus, which is in every way greatly superior to the apparatus I then showed, and which I believe, from reports which I have received of the apparatus used at the leading laboratories of the world for this same purpose, is capable of giving closer comparisons, and of being used to obtain the value of a single standard to a higher degree of accuracy than any other arrangement of apparatus in the world; with this improved apparatus in the hands of a skilful observer, I consider it entirely

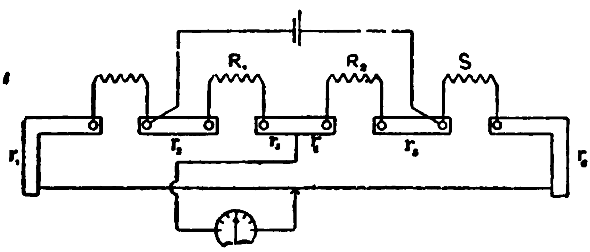


FIG. 1.

possible to determine the value of one coil in terms of another to an accuracy of $\frac{1}{400}$ per cent. and even greater.

As the details of the arrangement and method are not fresh in the memories of most of you, I will hastily run over the general theory of the method, and of its application by means of the early apparatus, and then set forth the improvements which have been made and embodied in this newest form. Let *Fig. 1* represent, diagrammatically, the orthodox slide wire bridge in which X is the unknown resistance (nearly equal to the coil S), to be accurately measured in terms of S, and R_1 and R_2 are resistances roughly equal to one another and to S. The balance reading will then fall near the centre of the bridge. The heavy copper end straps are of resistances which may be designated by r_1 and r_6, the resistance of the other connectors by

r_2, r_3, r_4 and r_5, as shown. When a balance is obtained, we have

$$\frac{R_1 + r_2 + r_3}{R_2 + r_4 + r_5} = \frac{X + r_1 + x_1 \rho}{S + r_6 + (L - x_1) \rho} \tag{1}$$

x_1 being the reading;

L being the whole length of the bridge wire;

ρ being the resistance of a single division of the bridge wire.

Reversing the position of X and S, and balancing again, we have

$$\frac{R_1 + r_2 + r_3}{R_2 + r_4 + r_5} = \frac{S + r_1 + x_2 \rho}{x + r_6 + (L - x_2) \rho} \tag{2}$$

From (1) we have

$$\frac{R_1 + r_2 + r_3}{R_1 + R_2 + r_2 + r_3 + r_4 + r_5} = \frac{X + r_1 + x_1 \rho}{X + S + r_1 + r_2 + L \rho} \tag{3}$$

and from (2)

$$\frac{R_1 + r_2 + r_3}{R_1 + R_2 + r_2 + r_3 + r_4 + r_5} = \frac{S + r_1 + x_2 \rho}{X + S + r_1 + r_2 + L\rho} \tag{4}$$

$$\therefore\ X + r_1 + x_1 \rho = S + r_1 + x_2 \rho \tag{5}$$

and

$$S - X = \rho\,(x_1 - x_2)$$

or

$$X = S - \rho\,(x_1 - x_2) \tag{6}$$

so that the unknown X differs from the standard S by exactly the resistance of the bridge wire over which the slider moves in changing from one position of balance to the other when the coils X and S are interchanged; we also see that the expression is entirely independent of the *length* of the bridge wire, and also of the resistance of the connecting coppers. We may, therefore, measure as small differences as we please by merely making the resistance of our bridge wire small enough.

I will now sketch the earlier apparatus, *Fig. 2.* This was a device for quickly and easily interchanging the two coils, X and S, of *Fig. 1.* Upon a suitable insulating base are

mounted a number of copper straps and plates as shown; these are so arranged as to place four coils in exactly the same relation to one another as in *Fig. 1.* The lettering upon the two figures is the same. The coils X and S have their terminals resting in mercury cups; the coils R_1 and R_2, being eliminated in the measurement, are simply fastened firmly into the binding posts. The galvanometer and battery circuits are as shown. In the

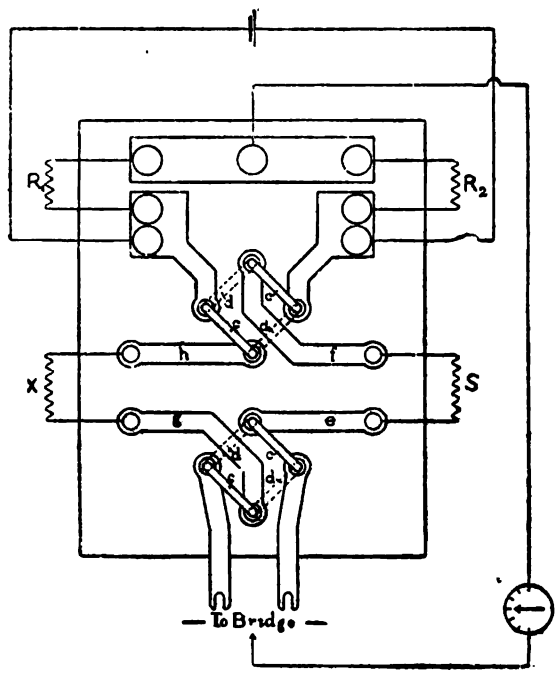


FIG. 2.

centre of the apparatus are seen two groups of mercury cups, each group forming a square; these groups are connected together, as shown, by the heavy copper rods C. By now running around the circuit from the left, clockwise, it will be seen that the order of the four coils is exactly the same as in *Fig. 1.* If, now, we alter the position of the heavy connecting rods C, to the position indicated by the dotted lines, the coils X and S will be interchanged as will be readily obvious by again following around the circuit. In

practice each *pair* of connectors is held in a little hard rubber platform, *C, Fig. 3*, so that but two movements are required to effect the change; being held loosely in the platform they will adjust themselves to the surface of the bottom of the cup, and thus make thoroughly good contacts. Inspection will show that this apparatus is a perfectly symmetrical arrangement, and that, consequently, the connector resistances need not be considered: thus, with the commutator rods as shown by the heavy lines, and passing around the circuit from the bridge, clockwise, we have in circuit on the left, g, X and h, the other pieces being very obviously *pairs*, and on the right f, S and e. Turning the commutator through 90° to the positions indicated by the dotted lines,

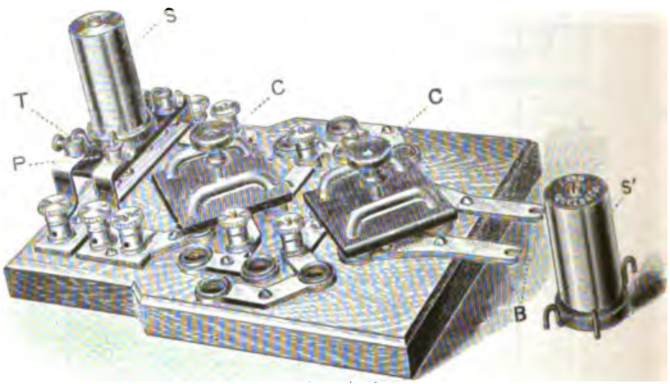


FIG. 3.

starting from the left again we have e, S and f, and from the *right* g, X and h; since $e = h$ and $f = g$, it is the same whether they are on one side or the other, and therefore only the resistances X and S have really been interchanged. To *use* this apparatus it is only necessary to insert the two slotted terminal straps into one of the gaps of an ordinary slide wire bridge. In the work which we have been doing we have been using a special form of slide bridge designed by myself, and having three wires, each a metre long, which can be thrown into multiple with one another if desired.

Having thus described the earlier form and arrangement of the apparatus I will now speak of its inconveniences and defects. The first one arises when we attempt to obtain

the value of the resistances of the bridge wire per unit division. This, of course, might be obtained by connecting the ends of the wire directly to a Wheatstone's bridge arrangement and obtaining its resistance by ordinary methods. The resistance, however, is necessarily very low, as we shall see from the following considerations: Suppose we have a standard ohm and a resistance of platinoid nearly equal to the ohm, whose temperature coëfficient we wish to exactly determine. We place our two coils in oil baths with both at (say) 15° C. and obtain a balance; we then carefully raise the temperature of the platinoid to (say) 30° C., and balance again. The difference, in terms of resistance of the bridge wire, will be the actual increase in resistance of the platinoid. The rise of resistance of platinoid per degree C. is about 0·00023; multiplying this by 15 and we have 0·00345 ohm as about the actual increase of resistance due to the raising of the temperature from 15° C. to 30° C. Let us suppose also that the value of the coëfficient must be obtained to the fifth decimal place, or in other words that the resistance 0·00345 must be measured with a maximum error a trifle less than 0·00008 of an ohm. With the average slide wire bridge a skilled observer is able to set the slider, it may be assumed, successively, with an error of setting not less than about $\frac{1}{10}$ mm. Consequently $\frac{1}{10}$ mm. of the wire must measure at least as low as 0·00008 ohm, and hence the whole wire 1,000 mm. long will measure 10,000 times this or $\frac{8}{10}$ ohm. To measure even as low a resistance as this even to $\frac{1}{25}$ per cent. is not at all an easy matter by ordinary methods. In practice the resistance of a metre wire should be as much less than the value given above as possible as a greater *length* of wire would then be used when X or S were changed; its non-uniformity would, consequently, become relatively less important, and errors of setting would bear a smaller ratio to the whole length used. It would also be much better, if possible, to measure the resistance of the bridge wire in terms of the resistance of the standard itself, as we would thus eliminate any difference of adjustment between the single standard and any box which we might use for the purpose of measuring the resistance of

the bridge wire by ordinary methods. We are, indeed, able to very accurately use this method and apparatus in measuring its own bridge wire. To do this we merely place a heavy short copper strap of negligable resistance in place of X and a resistance Q, somewhat less than the resistance of the single wire, at the right (diagram of *Fig. 1*). Taking our two balances as before, we have from (6)

$$Q - o = \rho\,(x_1 - x_2) \therefore \rho = \frac{Q}{x_1 - x_2} = \frac{Q}{\delta_1} \tag{8}$$

To find now, the resistance of Q place it in multiple with the standard S, at the right, and again determine the difference, in this case S_2, we shall have

$$\frac{Q\,S}{Q + S} = \rho\,\delta_2 \tag{9}$$

and eliminating Q between (8) and (o) we have

$$\rho = S \cdot \frac{\delta_1 - \delta_2}{\delta_1\,\delta_2}$$

A third way, which I have used a great deal, is to place a standard one and ten-ohm coil in multiple upon one side against a standard one-ohm coil upon the other. In the early form which I have described it was very difficult to accomplish any of this placing in multiple as there was but one pair of mercury cups upon a side; consequently, we were obliged to make an accessory double pair of cups with connectors to hook into the regular standard cups; this introduced another mercury contact, in itself a bad thing, and also an additional copper resistance which disturbed the symmetry of the apparatus, and hence, the rigid accuracy of the equations preceding. In the improved design of apparatus which I have here, *Fig. 3*, provision has been made for the placing, if desired, of two coils upon each side, and this in a way which does not in the least disturb the original symmetry of the apparatus. In the diagrammatic sketch of this, *Fig. 4*, there is shown a ten- and one-ohm coil in multiple on one side against a one-ohm on the other side; observe, also, that the cups are so placed that the coils clear one another perfectly, and have ample room

about them for the necessary oil or water-bath. The distance between these cups is one and five-sixteenths inches, the usual distance between terminal coppers of the B. A. form of standard, which distance will, for the sake of uniformity, probably be retained by all instrument makers for a long time to come.

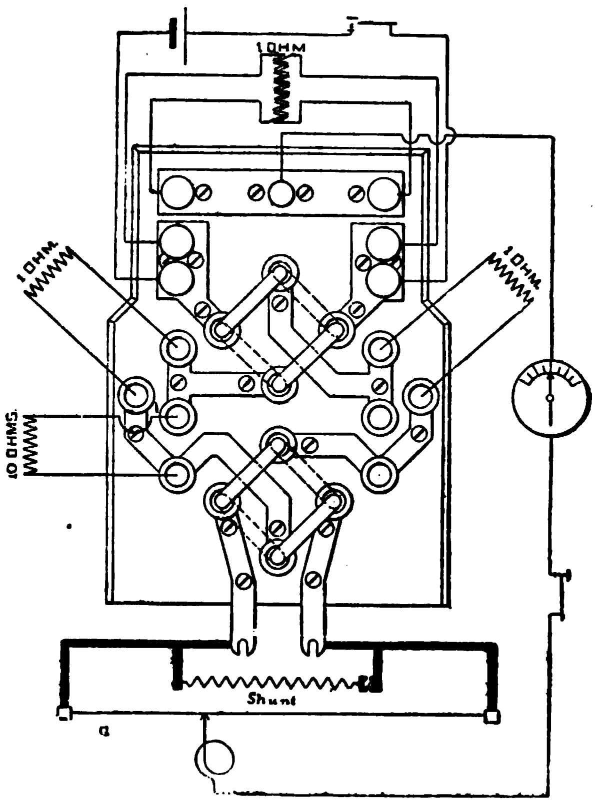


FIG. 4.

The resistance of the coils R_1 and R_2 disappears in the course of the measurement, as is seen from inspection of equations (5) and (6). It is hence not necessary that the *value* of these resistances be known; all that is desired is that they should be *approximately* of the resistance of the coils under comparison in order that the balance may fall near the centre of the wire, and that their resistance should

not change during the progress of the measurement. To insure this latter it is sufficient to wind the two coils upon the same spool, and in the first apparatus I ever made of this kind, while I was in the laboratory at Ann Arbor, these two coils were simply enclosed in a plain round wooden box. Later on it occurred to me, however, to place them upon a spool mounted upon a little stand having a pair of terminals upon each side fitting into the binding posts at *T*; the apparatus was thus compacted and made better appearing, and the coils could be more readily removed and others substituted in case standards of a greater or less value were to be compared. In this last design the spool itself is so made as to be removable from the *platform* instead of the whole platform having to be taken off. The terminals of the platform end in little copper binding posts *T*, which receive terminal rods coming from the coils themselves; these coils are wound upon a spool enclosed in a small cylindrical brass case *S*, mounted upon a rubber sub-base *P*. Each case has engraved upon its top the values of the enclosed resistances, as " 2 one-ohms, " " 2 ten-ohms, " etc. If we desire to adjust ten-ohm standards instead of one-ohm standards, we merely unscrew the little milled head screws, at the side of *T*, lift off the spool and replace it by another one of suitable value.

I stated above that, in our laboratory, we are using a three-wire slide metre bridge of special design. At one time we thought this a very fine thing, but have modified our opinion and now consider it a very ordinary piece of apparatus. It is, to be sure, much better than the average bridge to be met with; what I mean is that compared with what we have learned how to make, this bridge is quite a poor affair. In the first place, I believe any design of a Wheatstone's bridge which is intended for exact work is fundamentally bad if it makes use of a straight wire of any length stretched between two points. I have several reasons for this belief. A bridge used in the average laboratory cannot but be subjected to considerable variations of temperature from one time to another; sometimes this will not be over 5° or 10° for an entire month at a time;

again it may be 20° in about as many hours. As the bases of most slide-wire bridges have been of wood having a coëfficient of expansion considerably different from those of the German silver or platinum iridium wires mounted upon them, it is evident that their temperature variations must produce, at times, considerable strain upon the soldered junctions of wire and end pieces when the wire has been tightly stretched, and it *must* be tightly stretched if good work is done. Probably the greatest strain, however, does not arise so much from the difference of expansion coëfficients as from the change produced in the dimensions of the wooden support by reason of its absorbing or giving out moisture; for purposes of instrument construction it is practically impossible to find wood so well seasoned as not to deform in a very short time. It is, consequently, not surprising that very few straight slide wires ever remain in position very long. In fact, I have never yet seen a straight wire bridge upon a wooden base, with wire stretched tightly enough to make an accurate measurement, whose wire would hold fast without pulling out for a week. The only remedy is to either place the wire upon a compensating base or else to arrange the wire so that it may be slackened when not in use. In the "three-wire" bridge previously spoken of, the wires were fastened to sliding copper end plates which could be tightened and fastened to the end pieces proper by having copper connecting straps. But this having to tighten the wires is a nuisance, requires some strength, and is apt to mean slightly different settings and consequent lengths of wire at different times. I have here a design of a three-wire straight bridge which we have just completed and from which the first instrument is now being made in our shop. Instead of a solid base the support for the wires will be a skeleton frame work of brass rod, the coëfficient of expansion of which is not very far distant from that of the alloys which are usually used for bridge wires. A straight-wire bridge has, however, still another defect, to my mind, fully as serious as the one mentioned. This is the tendency to the development of thermal currents, particularly where the wire is joined to the end coppers;

the ends of the wire being a metre apart it is entirely possible and indeed probable that differences of temperature will exist in the air at the two ends of the wire of sufficient amount to develop thermal electro-motive forces of very appreciable values. To make perfectly clear how important a consideration this is I must again refer to the theory of this "Carey-Foster" method. Let us assume that we are comparing two standard ohm coils together and that we wish to know one in terms of the other to an accuracy of $\frac{1}{200}$ per cent., *i. e.*, that we must have a deflection of the galvanometer needle when the slider is but $\frac{1}{20000}$ ohm from perfect balance. We will assume that we are using one cell of battery giving about one volt effective E. M. F. at the junction with the bridge arms. Since there are two ohms on each side the fall through $\frac{1}{20000}$ ohm is $\frac{1}{40000}$ volt. Let us also assume the bridge wire to be German silver, and the terminal ends to which the wire is fastened copper. The thermal E. M. F. of this couple assuming that the one end is at a temperature of 19° C. and the other at 21° C., a difference of but 2° C. is, according to Professor Tait's table of thermo-electric heights,*

$$\begin{array}{r} \text{German silver} - 1{,}207 - 5{\cdot}12\,t \\ \text{Copper} + \underline{\phantom{1{,}}136 + {\cdot}95\,t} \\ - 1{,}343 - 6{\cdot}07\,t \end{array}$$

E. M. F. per degree $-\ 1{,}343 - 6{\cdot}07 \times 20 = 1{,}464$ C. G. S.

E. M. F. of couple $1{,}464 \times 2 = 2{,}928$ C. G. S. $= \frac{3}{100{,}000}$ volt.

This value just obtained is a trifle greater than the E. M. F. which must be detected by the galvanometer and will, of course, throw our observations out by exactly the same amount and prevent our obtaining the required accuracy. If this happens when there is only 2° difference between the ends and when but $\frac{1}{200}$ per cent. is aimed at, how will it be when there is 4° or 5° difference, as there often is, and an accuracy of $\frac{1}{800}$ or $\frac{1}{400}$ per cent. to be attained, and in addition innumerable other thermal E. M. F.'s due to other portions of the apparatus?

* Everett's *Units and Physical Constants*, 2d ed., pp. 174.

Of course, there are other ways of eliminating the influence of thermal currents. The simplest is to use the galvanometer in place of the battery and to close the battery circuit upon the bridge wire. This plan is, however, not to be recommended. Another good way is to reverse the battery current, the thermal E. M. F., thus acting at one time *with* and at another *against* the battery E. M. F.; the mean of the two is then the balance reading. This is easily accomplished in the apparatus which has been diminished by first taking readings with commutators turned parallel and then with commutators at right angles; *e. g.*, (*Fig. 5*), there would be four commutator positions necessary, as below:

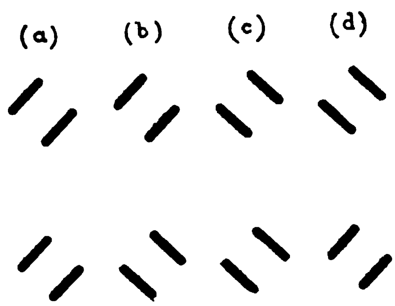


FIG. 5.

The difference of the mean of (*a*) and (*b*) and the mean of (*c*) and (*d*) would represent the desired difference between *X* and *S*, which we desire.

The orthodox straight-wire bridge also occupies considerable space and spreads the apparatus necessary for many of the more common measurements out in an undesirable manner, besides in the case of regular Wheatstone bridge work requiring one to get himself into all sorts of impossible positions in order to obtain and read his balance. On account of all these reasons, I personally favor a wire bridge, having the wire bent one or more times about a circle or cylinder rather than the straight-wire pattern. A circular-wire bridge, if well made, does all that the straight pattern will do and does it much more conveniently; it occupies but little space and brings the readings where they can easily be read; the ends of the wire are close together, so that there is prac-

tically no difference in temperature between them and the form is necessarily such that the wire cannot pull out of the end junctions. The contact also is usually a rolling wheel contact giving a tangent point of contact, and hence is not liable to injure the wire, as are most of the cutting "knife edge" contacts on the usual forms of straight bridge. These conclusions as to the relative efficiency of straight and circularly laid wires in slide-wire apparatus are not merely theoretical; they are practical, having been founded upon my own personal experience with both types in the making of very accurate measurements, and upon the experience of those associated with me, who are using the method every day in commercial work.

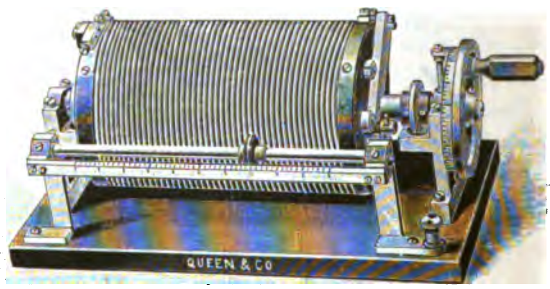


FIG. 6.

I have, therefore, designed and constructed a cylindrical arrangement of bridge wire to go with this latest form of commutating device just described. This is shown in *Fig. 6*, and in diagram in *Fig. 7*. The wire is here coiled upon a polished hard rubber cylinder 4 inches in diameter and 7 inches long; this cylinder is highly polished and the wire stretched in a screw thread cut in its surface. There are fifty turns of wire upon the cylinder. In front of the cylinder is a scale running the entire length of the cylinder, and between the cylinder and scale a small wheel sliding upon a bar carried by the same supports as the scale. This wheel bears snugly against the wire, the end supports being strips of spring brass. Its circumference is platinized and turned to as true a circle as possible, so that the tangent contact is very sharp and definite. As the cylinder is caused to revolve upon its axis, by turning the handle at the end, the little

contact wheel travels along the scale always in contact with the wire. The long scale indicates how many complete turns have been made. In order to obtain the fraction of a turn the wheel at the end is divided into 100 parts and each of these parts is easily divided, by the eye, to tenths. This graduation is read by reference to a zero mark at its side, visible in the cut. The bridge wire is thus divisible into $50 \times 100 \times 10 = 50{,}000$ parts. In order, however, to measure accurately the extremely small resistances represented by the increase of resistance of (say) a platinum silver one-ohm standard for 10° C. increase of temperature, we must have a lower resistance bridge wire than could be obtained by bending any *flexible* wire upon a cylinder but four inches in diameter. The wire has, consequently, been

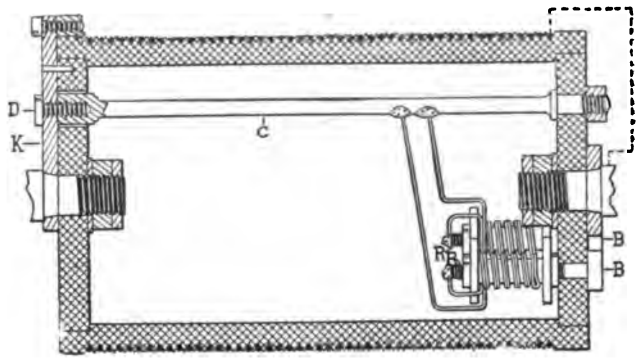


FIG. 7.

shunted by two shunts placed inside the cylinder itself; these shunts are such that the total resistance of the bridge wire may be either one-ohm or $\frac{1}{10}$ ohm, as desired, and are arranged so that either may be used by simply plugging in a small plug at the end of the cylinder. If we use the $\frac{1}{10}$ ohm shunt the smallest difference measurable with the combined apparatus is $\frac{1}{50000} \times \frac{1}{10}$ ohm $= 0{\cdot}000002$ ohm; it is thus easy to measure with great accuracy extremely small differences between two coils or to determine temperature coëfficients, even though extremely small.

The method of arranging the shunts in this apparatus is worthy of notice; they are so placed that their adjustment, by the maker is easy and convenient. Referring to *Fig. 6*,

the shunts are each mounted upon rods *R*, screwing into the end blocks *B*; one end of each shunt is soldered to its rod. The other ends of each shunt are soldered to the rod *C*. In adjusting, the right-hand head of the cylinder is slipped out of position, carrying with it the shunts and rod *C*; the shunts are adjusted as accurately as possible and the head slipped back. As the head slips into place the rod *C* shoulders against a heavy copper strap *K*, connecting with the left-hand end of the bridge wire. A copper screw *D* then taps into both the strap *K* and rod *C*, thus making a clean, fresh screw connection between them; a careful measurement of the total resistance is now made, the amount of necessary correction noted and the head again slipped out. A very few trials will suffice to get the desired resistance with great accuracy.

The heavy copper end straps, to which the ends of the bridge wire are soldered, are coned very tightly upon the shafts of the cylinder. These end shafts are of solid copper one-half inch in diameter, and revolve in heavy copper bearings brazed directly to the straps going to the commutating attachment. On the inside of each bearing is formed a massive mercury cup, in which revolves a copper ring $1\frac{3}{8}$ inches in diameter and $\frac{1}{8}$ inch thick: these rings have been sprung upon each end bearing and fit very tightly. Over half a square inch of their surface is always under the surface of the mercury, which is always kept at the same height. The surface of copper contact is so large and the thickness of mercury so small that the resistance at these places is negligable; it is also constant. A sliding brush contact will not answer for work of this kind, as the contact resistance is apt to be variable. In order to prevent the mercury from spreading, by capillary attraction, over the adjacent copper surfaces, each copper ring is clamped, just outside the shaft, between rubber washers recessed and filled with sticky wax. This wax, pressing against the copper, will, it is hoped, aided by the thick bands of lacquer, keep the mercury in its proper place

Particular attention must be drawn to the fact that every particle of metal forming, in any way, part of the circuit o

in contact with it, is of copper in both the commutator and cylindrical bridge with the exception of the wire itself. This is necessary not only to keep the resistance of the circuit small, but also to avoid *thermal currents and contact E. M. F.'s.* In the earlier apparatus referred to in the first part of this paper, it has been impossible to do the highest grade of work without thoroughly wrapping a large part of it in cloths or paper to keep down the thermal currents, and this, despite the fact that about the only metal *except* copper, was in the binding posts; these, however, are sufficient to generate disturbing E. M. F.'s of sufficient magnitude to effectually mask the results desired, and it was seen to be imperatively necessary to get rid of this *entirely.* In the present apparatus the binding posts, connectors, cups,

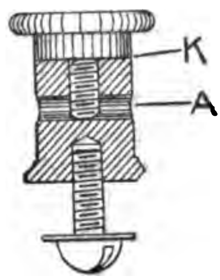


FIG. 8.

shafts, shunt rods C and K, the terminal blocks of the shunt coils and all are copper; only the junctions of the wire itself can possibly give trouble, and this, experience has shown, need not be feared in the cylindrical bridge.

It is obvious that by simply replacing X and S, *Fig. 1*, by negligable resistances we convert the arrangement into the simple Wheatstone's bridge. Hence, in the apparatus in *Fig. 3* we need but to place short, heavy copper wires in place of the standards on each side to enable us to use the device for ordinary work.

Often it is desirable to measure spools of wire quite accurately (say to $\frac{1}{20}$ per cent.), as, for instance, in the adjustment of a high-grade resistance box, where the coils must be as accurate as possible before putting into the set since any adjustment *then* would involve the loosening and

re-making of a solid joint and much inconvenience. With this apparatus this work can be done in one-fifth the time necessary with the usual apparatus, and with a more certain accuracy. Since, in such cases, it would not be worth while to solder wire ends to heavy coppers for immersion in the mercury cups, and since, indeed, the accuracy wanted does not require it, binding posts have been provided for this purpose just back of the mercury cups. These posts are of the "double grip" style, designed by Queen & Co. (shown in section in *Fig. 8*), and will catch the finest wires securely, either in the hole A or between the surfaces K; the resistance of quite heavy copper conductors may thus be measured.

Many results obtained with and showing the performanec of this apparatus might be given. The following, transcribed from one of our laboratory note-books, is sufficient, however, to show the exceedingly high accuracy obtainable. It is the record of a standardization of a coil recently sent to us by one of the large universities for an exact determination of its value. The data, as will be observed, were obtained on four different days, when, of course, minor conditions and the personal equation were likely to be very different.

ELIOTT OHM, NO. 106.

(*a*) October 27, 1892.			
Millimetres to balance, . .	— 358·3	value in ohms, . .	— 0·01250
Temp. of standard (E No. 186),	13°·0 C.	value of standard, . .	0·99675
Temp. of ohm (No. 106), . .	13°·25 C.	value of ohm No. 106,	0·98425
(*b*) October 27, 1892.			
Millimetres to balance, . .	— 355·0	value in ohms, . .	— 0·01239
Temp. of standard (E No. 186),	12°·7 C.	value of standard, .	0·99667
Temperature of ohm No. 106,	13°·3 C.	value of ohm No. 106,	0·98428
(*c*) October 27, 1892.			
Millimetres to balance, . .	— 429·3	value in ohms, . .	— 0·01502
Standard (A), ...	——	value in standard, .	1·00608
Temperature of ohm No. 106,	42°·1 C.	value of ohm No. 106,	0·99106
(*d*) October 27, 1892.			
Millimetres to balance, . .	— 424·8	value in ohms, . .	— 0·01487
Standard (A), ...	——	value of standard, . .	1·00608
Temperature of ohm No. 106,	42°·3 C.	value of ohm No. 106,	0·99121

(*e*) October 28, 1892.

Millimetres to balance, . .	— 171·4	value in ohms, . .	— 0·02091
Standard (A), ...	——	value of standard, . .	1·00608
Temperature of ohm No. 106,	18°·0 C.	value of ohm No. 106,	0·98517

(*f*) October 28, 1892.

Millimetres to balance, . .	— 596·3	value in ohms, . .	— 0·02087
Standard (A), ...	——	value of standard, . .	1·00608
Temperature of ohm No. 106,	18°·1 C.	value of ohm No. 106,	0·98521

(*g*) November 7, 1892.

Millimetres to balance, . .	— 293·9	value in ohms, . .	— 0·01029
Standard (B), ...	——	value of standard, .	0·99588
Temperature of ohm No. 106,	18°·1 C.	value of ohm No. 106,	0·98559

(*h*) November 10, 1892.

Millimetres to balance, . .	— 284·3	value in ohms, . .	— 0·00995
Standard (B), ...	——	value of standard, .	0·99587
Temperature of ohm No. 106,	19°·5 C.	value of ohm No. 106,	0·98592

(*i*) November 10, 1892.

Millimetres to balance, . .	— 284·8	value in ohms, . .	— 0·00997
Standard (B), ...	——	value of standard, .	0·99585
Temperature of ohm No. 106,	19°·3 C.	value of ohm No. 106,	0·98588

ACCURACY OF RESULTS.

Date.	*Test.*	*Value.*	*T—° C.*	*Accuracy of Agreement with Temperature Coëfficient Applied Between.*
October 27, 1892	(*a*)	0·98425	13°·25 C.	
				(*a*) and (*b*) $\frac{1}{500}$ per cent.
October 27, 1892	(*b*)	0·98428	13°·3 C.	
October 28, 1892	(*e*)	0·98517	18°·0 C.	
				(*e*) and (*f*) $\frac{1}{500}$ per cent.
October 28, 1892	(*f*)	0·98521	18°·1 C.	
November 7, 1892	(*g*)	0·98559	18°·1 C.	
				(*g*) and (*h*) $\frac{1}{500}$ per cent.
November 10, 1892	(*h*)	0·98592	19°·5 C.	
November 10, 1892	(*i*)	0·98588	19°·3 C.	(*g*) and (*i*) $\frac{1}{1000}$ per cent.
				(*h*) and (*i*) $\frac{1}{1000}$ per cent.

DETERMINATION OF TEMPERATURE COËFFICIENT.

(1) From (*c*) we have . . . . 0·99106 ohms at 42°·1 C.
From (*e*) we have . . . . 0·98517 ohms at 18°·0 C.

Difference is . . . . 0·00589 ohms for 24°·1 C.

$$\therefore \text{Temperature coëfficient} = \frac{0{\cdot}00589}{24{\cdot}1 \times 0{\cdot}98517} = 0{\cdot}000252$$

(2) From (d) we have . . . . 0·99121 ohms at 42°·3 C.
From (f) we have . . . . 0·98521 ohms at 18°·1 C.

Difference is . . . . 0·00600 ohms at 24°·2 C.

$$\text{Temperature coëfficient} = \frac{0{\cdot}00060}{24{\cdot}2 \times 0{\cdot}98521} \; 0{\cdot}000252$$

SUMMARY.

Between October 28th and November 7th, the temperature was, at times, very low. This caused the increase noted in (g), (h) and (i) over (e) and (f). The fall between (a), (b) and (e), (f) was due to the heating to which the coil was subjected in (c), (d). This coil, No. 106, was of platinum silver, and this *permanent increase* if subjected to low temperatures and decrease if too high temperature are well-known characteristics of the alloy. The present value of the coil is given by (g), (h), (i): this value holds, providing the limits 12°·0 C. and 25°·0 C. are not exceeded. After noticing the permanent change in resistance above referred to, I wrote to Professor Carhart, who had sent us No. 106, telling him of it and saying that it probably occurred as a result of the heating necessary in getting its temperature coëfficient, but did not give him the coëfficient we had obtained. In his letter of reply, he said: "I meant to tell you not to heat the standard, as we have very carefully determined its coëfficient. It is not over 0·00025, I think." This, as contrasted with our value given above, is a difference of but $\frac{1}{5000}$ per cent., and shows how close work can be done with the apparatus in the hands of different observers in different places at different times.

Since the preceding portion of this paper was written, considerable additional work of the character which has been discussed has been done under my direction, with the previously described, and kindred forms of, apparatus. The results have been even more gratifying than those which have been given.

In connection with the work another new design of the apparatus has been produced which may seem to some to offer points of further advantage. The new design is shown in perspective in *Fig. 9*. As will be noted, the bridge

and commutator are here combined in one piece so that the apparatus is complete in itself. The arrangement is, upon

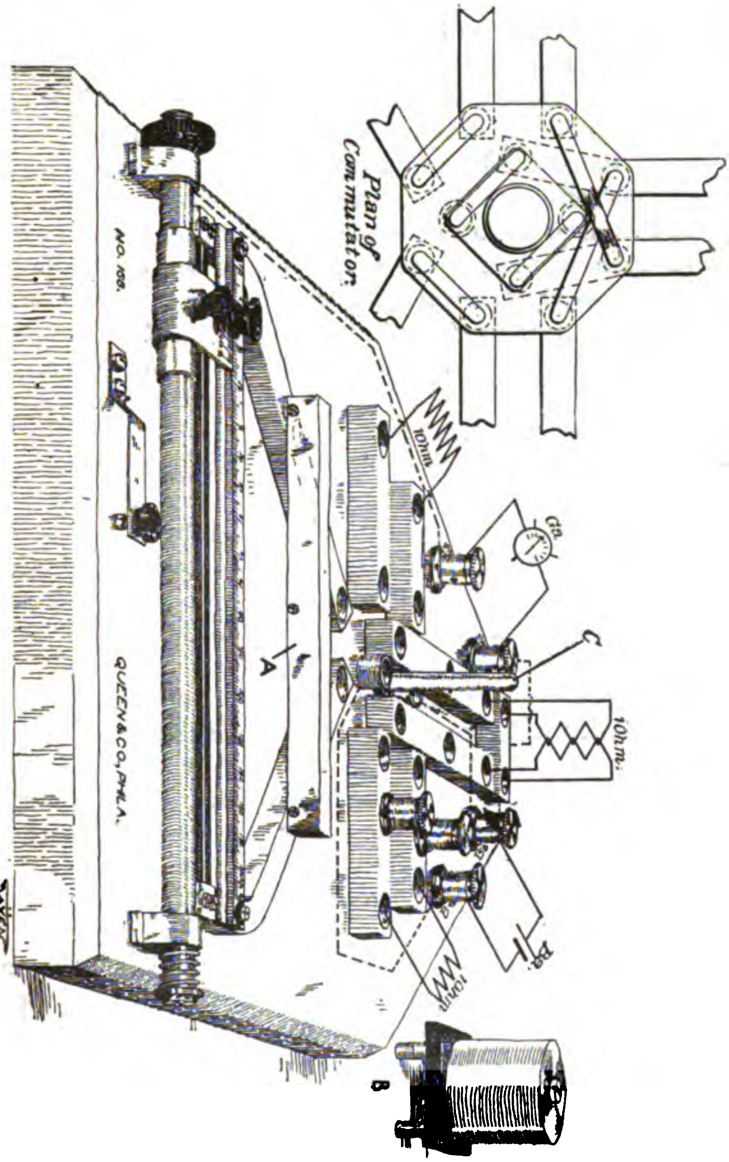


FIG. 9.—Improved bridge for comparing standards of resistance.

the whole, exactly the same as that shown in *Fig. 3*, the principal differences between the two being in compactness

and simplicity of construction. The two commutators of *Fig. 3* are so arranged that but *one* movement is required to effect the commutation, instead of two. This commutator, moving upon the rod *C*, really consists of two parts, one fitting upon the other. By using the upper head the whole platform is moved and the coils *X* and *S* (*Fig. 1*) are interchanged. By moving the lower head only, the ***battery*** alone is commuted, thus enabling us ***perfectly*** to eliminate all thermal effects. This is a very important matter, as the E. M. F.'s used are all so small that thermal potentials may prove greater than those employed, as was earlier pointed out. ***The ability to commute the battery only is, consequently, of vital importance if good results are to be attained.*** The pattern shown in *Fig. 3* accomplished this by four movements (*Fig. 5*), as was shown; the new design, therefore, enables us to save two movements.

The two accessory coils *S*, *Fig. 3*, are here mounted in much the same way, but their terminals simply drop into mercury cups instead of being gripped by binding posts. The two coils under comparison are placed at the sides as before; by means of the binding posts a coil may be placed in multiple with the standard in determining the resistance of the bridge wire by the second method.

The bridge wire is permanently a part of the apparatus; it is twenty centimetres long. The slider is provided with a vernier by means of which the wire may be read to one-twentieth millimetre. A very fine adjustment of the slider may be obtained by means of the screw nut attached to the rod upon which the slider usually moves, but to which it may be rigidly clamped if desired. In order to have as low a resistance bridge wire as may be necessary, shunts are used, as in the cylindrical bridge, *Figs. 6* and *7*. The shunt is a wire of suitable size mounted upon a rubber strip and covered by a little zinc box *A*; two copper terminals, to which the shunt is attached, drop into two mercury cups so as to shunt the bridge wire. Different shunts may be used for different ranges of work. Each shunt may have stamped upon it the value of resistance of unit bridge wire division obtained by its use. This mode of varying the resistance

of the bridge wire is much superior to the employment of a number of wires which may either be bodily changed or with which may be used an adjustable slider which may be placed so as to run above any particular wire desired. The greatest advantage lies in the fact that using shunts it becomes worth while to work down the bridge wire until it is perfectly uniform in resistance; a shunt will then merely lower its total resistance. If the wires are bodily changed either this large amount of labor must be applied to each one or else a different calibration curve must be used for each wire. Another objection would be the difficulty of always getting the same contact resistances at the ends of the wire; if made with mercury they would be variable, owing to the instability produced by the contacts of the slider.

The apparatus is very simple to make, all the copper work being ordinary market-copper bars one-half inch square and bent into the required shape, the cups being drilled in the bars themselves. It is also very compact, measuring but 11 x 10½ inches over all.

REPORT OF THE ELECTRICAL SECTION OF THE FRANKLIN INSTITUTE FOR THE YEAR 1892.

To the President and Members of the Franklin Institute:

The Secretary of the Electrical Section begs leave to present the following report of the Section's proceedings for 1892.

Officers.—The business of the Section has been carefully and successfully conducted by the following officers:

President,	PROF. EDWIN J. HOUSTON.
Vice-Presidents,	MR. C. W. PIKE, MR. CARL HERING.
Secretary and Treasurer,	PROF. L. F. RONDINELLA.
Conservator,	DR. WM. H. WAHL.

Membership.—The Section now numbers fifty-one active members and eighteen associates, or a total of sixty-nine members. This is a slight increase over that at last report, fourteen names having been added to, and thirteen dropped from the roll during the year.

Finance.—The following is a summary of the Treasurer's report:

Cash in hand, December 30, 1891,	$15 68
Received from initiation fees, dues, etc.,	97 12
	$112 80
Paid for printing, clerical work, etc.,	103 93
Balance on hand, January 1, 1893,	$8 87

Meetings.—One special and ten regular meetings have been held during the year, at which there has been an average attendance of twenty-six. At the regular meeting of May, the Section's By-Laws were amended by changing the time for regular meetings from the first to the fourth Tuesday of each month, excepting July and August.

Papers.—The following is a list of the papers that have been presented at the meetings of the Section, those indicated by an (*) having been printed in full in the *Journal of the Franklin Institute*, and in vol. ii of the Section's *Proceedings:*

"Recording Volt- and Ammeters." By H. S. Hering.

* "Electro-Magnetic Machinery." By Wm. S. Aldrich.

* "An Early Conception of the Magnetic Field." By Edwin J. Houston.

"Notes on the Power Transmission Plant at Niagara." "The Frankfort Electrical Exhibition." "Burton's Process of Electric Forging." By Carl Hering.

* "On the Variable Action of Two-Coil Solenoids." By Wm. S. Aldrich.

* "The Constant Shunt Method for the Measurement of Continuous Currents." By C. W. Pike.

* "Cerebral Radiation." By Edwin J. Houston.

"The Oerlikon Works' Proposal for the Niagara Transmission Plant." By Carl Hering.

* "Dynamo and Motor Calculations." By C. H. Bedell.

"Experiments with High Potential Alternating Currents." (*Letter.*) By Elihu Thomson.

* "On Polyphased Currents." By P. Winand.

* "Ampère-Centimetre: A Measure of Electro-Magnetism." By Carl Hering.

"The Magnetic Influence of So-called Non-magnetic Substances." By E. G. Willyoung.

* "A Graphic Representation of the Magnetic Field." By Edwin J. Houston.

* "The Physiological Effects of Alternating Currents of High Frequency." By Edwin J. Houston.

* "Magnetic Disturbances on Weston Measuring Instruments." By C. W. Pike.

"A Home-made Thomson Reflecting Electrometer." By D. A. Partridge.

* "On Polyphased Currents." (Second part.) By P. Winand.

* "Additional Notes on the Graphic Representation of the Magnetic Field." By Edwin J. Houston.

"The Plant and Process for Aluminum Plating the Ornamental Iron Work for the City Hall." By Wm. H. Wahl.

* "Some Curiosities in Early Electro-therapeutics." By Edwin J. Houston.

* "A New Ballistic Galvanometer." By E. G. Willyoung.

* "On the Measurement of Energy in the Three-phase System." By P. Winand.

* "Some New Apparatus for the Most Exact Comparison and Adjustment of Resistance Standards and the Determination of Temperature Coëfficients." By E. G. Willyoung.

* "Errors in the Determination of Areas from Measured Diameters." By O. T. Louis.

* "Recent Improvements in the d'Arsonval Galvanometer." By Nelson H. Genung.

"Some Principles that must be Observed in the Construction of a Good Closed Circuit Battery, and some New Portable Dry Cells in which they are Applied." By Edwin F. Northrup.

In addition to this, many interesting queries from the *Question-Box* have been discussed, and views and experience on practical subjects have been exchanged.

Outlook.—The recent slight increase in the Section's dues will considerably improve its financial resources, and systematic efforts are now being arranged by which the new committees will probably be able to increase the number of new members and arrange more attractive programmes for the meetings of 1893. The outlook, therefore, at the end of this second year of the Section's existence is very encouraging.

Respectfully submitted,

L. F. RONDINELLA,

Secretary and Treasurer.

VOL. 3. 1893.

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OF THE

FRANKLIN INSTITUTE.

Vol. III. January to December, 1893.

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Incorporated,
PHILADELPHIA.

INDEX.

Vol. III, 1893.

CHARLES A. COULOMB.

(1736–1806.)

PROCEEDINGS

OF THE

ELECTRICAL SECTION

OF THE

FRANKLIN INSTITUTE.

[*Stated meeting, held Tuesday, January 24, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 24, 1893.

Mr. E. G. Willyoung, President, in the chair.

Present, thirteen members and visitors.

The minutes of the previous meeting were read and approved.

The Secretary and Treasurer presented his annual report for 1892, which showed the Section to be in an active and prosperous condition. It was accepted and referred for publication.

The Treasurer reported the cash balance in the treasury, and presented bills for printing and clerical work, which were approved and ordered paid.

The Committee on Admissions reported two elections to membership since last meeting.

Mr. R. C. Hindley's resignation of active membership was presented and accepted.

A communication was read from the Secretary of the Institute, desiring information as to whether the Section would wish to publish an annual volume of its proceedings for this and future years, as the matter would all be printed in the monthly *Journal of the Institute*, and sent gratuitously to each member. Upon motion, the President and Secretary were appointed a committee to confer with the Publication Committee upon this subject.

On account of ill health from over-work, Prof. Rondinella regretfully offered his resignation as Secretary and Treasurer of the Section, to take effect upon the election of his successor at the February meeting. It was accepted with regret.

Mr. Edwin F. Northrup read the second part of his paper on "Some Principles that must be Applied in the Construction of a good Closed-circuit Battery, and some new Portable Dry Cells in which these Principles are Applied." Referred for publication. The paper gave the results of a most complete series of experiments, and was discussed by Messrs. Stradling, Willyoung, Billberg and Winand.

Prof. Geo. F. Stradling's paper, on "The Migration of the Ions," was deferred until next meeting.

Upon motion a committee of three was appointed to prepare and present a review of each month's electrical progress at the regular meetings of the Section.

The meeting then adjourned. L. F. RONDINELLA, *Secretary.*

SOME PRINCIPLES THAT MUST BE OBSERVED IN ORDER TO MAKE A GOOD CLOSED-CIRCUIT BATTERY, AND A NEW PORTABLE DRY CELL DESCRIBED IN WHICH THESE PRINCIPLES ARE APPLIED.

BY E. F. NORTHRUP.

[*A paper read before the Electrical Section, Dec. 28, 1892; Jan. 24, 1893.*]

The different types of primary batteries now upon the market are very numerous. Those acquainted with the subject know that all are more or less defective and that few, if any, give the efficiency that the theory of galvanism would seem to promise. Much excellent and exhaustive work has been done in determining the laws of electrolytic action and the general principles of chemical electricity, but fewer persons with the requisite chemical and mechanical knowledge have devoted themselves to the actual construction of cells which shall be free from practical defects and closely realize the theoretical possibilities.

The following general considerations may help to indicate the necessary limits to improvements in batteries and the paths in which to make an advance.

Prof. F. B. Crocker has shown, in a paper published in vol. v of the *Proceedings of the American Institute of Electrical Engineers*, the necessary cost of electric energy obtained by chemical means, and has reached the conclusion that primary batteries can never approach the dynamo in respect to economy or efficiency. There are, however, numerous cases, such as bell work, telephone, telegraph, medical and testing work where the cost of electric energy

is of a secondary consideration and where a thousand watts may be worth as many dollars.

If a cell is to give a constant current, or in short, be an efficient generator of electricity, there are certain cardinal principles which must be observed. Most of the literature upon batteries states how they *have been* made, not how they *should be* made; it being customary to describe the construction of special cells rather than the broad principles of application to all types. The following is an endeavor to briefly indicate these principles:

All substances may be divided into (1) non-conductors; (2) conductors which are not decomposed by the passage of an electric current; (3) electrolytes or conductors which are decomposed by the passage of a current. A circuit made up of substances of the second class can never maintain a current except by the application of a foreign force or source of electro-motive force. If it did, the result would be perpetual motion. This source of energy outside of the circuit may be in the form of heat that is applied to the junction of two dissimilar metals in the circuit, in which case there is thermo-electric current. If, now, a substance of the third class, an electrolyte, is introduced into a conducting circuit of the second class, and a current is made to pass through the entire circuit, the electrolyte is decomposed, according to a well-known law. But it is not necessarily true, on the other hand, that because the electrolyte of a circuit decomposes a current will flow. The energy of decomposition may take the form of heat at the seat of the chemical action and then there is no current. This would be the case if two similar pieces of zinc, which made up part of a conducting circuit, were dipped in a strong solution of hydrochloric acid. Rapid decomposition of the electrolyte would ensue, but no current would flow. The condition essential in order that the energy of decomposition may take the form of a galvanic current, is that the decomposition which results shall be due to a *stress* in the electrolyte brought about by an unequal attraction of the two electrodes for the different constituents, or ions, as they are called, of the electrolyte. In order that this

unequal attraction may be exerted, the electrodes must be at, what is called, a different potential from each other. This difference of potential may be brought about by the aid of an external source of electro-motive force, such being the case with the differently charged electrodes of a voltameter. Or, the two electrodes may tend inherently to maintain themselves at unlike potentials. Looked at from a chemical point of view, this inherent difference of potential possessed by the electrodes is the same thing as their unlike attraction or chemical affinity for the negative atoms or ions. The reason why different elements thus possess different potentials, or what is very probably the same thing, unlike degrees of chemical affinity, is not understood, but it is the fundamental fact which renders galvanic action possible. In short, the true source of the electric energy in a galvanic cell is to be found in the *unequal* chemical affinity which the two electrodes have for the atoms or ions of the electrolyte. Zinc and copper, for example, both attract chlorine, but zinc much more than copper, and hence negatively charged chlorine atoms will move from copper to zinc in an electrolyte of HCl. In the case of a $Zn/H_2SO_4/PbO_2$ couple, zinc has an affinity for SO_4, and PbO_2 has no affinity for that, but possesses a strong attraction for H_2, hence as each element pulls towards itself unlike ions, there is a strong stress in the electrolyte which means a correspondingly high electro-motive force.

The energy of the decomposition, when this is due only to the difference of potential of the electrodes, which produces the stress in the electrolyte, determines the force with which the current is urged forward, and a formula has been given by Lord Kelvin with which the electro-motive force of any combination can be calculated. (See Prof. F. B. Crocker's article, mentioned above.) This formula, however, only holds good in the case of a reversible element, viz: a cell in which all the energy of decomposition takes an electrical form, so that a reversal of the current will, theoretically, restore the cell. But under the ordinary conditions, as given above, an electrolyte will not continue to decompose, and the current at once ceases. The

reason for this is that the constituents into which it is decomposed, the ions, are deposited upon the surfaces of the two electrodes. These electrodes, if originally of a different potential from each other, are soon brought by this deposit of ions upon them to the same potential, for the ions themselves, being reckoned in the tension series, are always of opposite potential to the electrode upon which they are deposited. But if these ions, by any means chemical or mechanical, are removed as fast as they are deposited, electrical equilibrium cannot be established and the current will continue to flow.

This brings us to the three essential features of any galvanic arrangement which will furnish a continuous current: (1) A medium capable of decomposition, and which is called the electrolyte. (2) Two undecomposable conductors which make contact with this electrolyte and which are removed from each other more or less in potential, the farther the better. (3) Some source of energy, chemical or mechanical, which shall remove the ions as perfectly as possible and prevent electrical equilibrium from being established; in short, a depolarizer.

If the cell is to be efficient, each of these three parts must act efficiently. The electrodes must be removed from each other in potential as far as possible, the electrolyte must be easy to decompose, the depolarizer must be active, and all three parts must have good conductivity.

Theoretically, two depolarizers are required, one for the positive electrode to remove the negative ions, and one for the negative electrode to remove the positive ions. Practically, only one is required, for the positive electrode has such a strong affinity for the negative ions which form upon it that its own atoms unite with the negative ions, the electrode itself being thus consumed or burned, and this consumption is the continued source of energy at the positive electrode. But, unfortunately, a like action does not take place at the negative electrode, when such electrode is an element, for carbons and the metals capable of forming the negative electrode do not have a sufficiently strong chemical affinity for the positive ions to unite with them in a like

manner. There is one exception to this in the case of arsenic, when it is used as the negative electrode. For the positive hydrogen atoms will unite with metallic arsenic to form As_2H_4, and as the negative atoms at the same time unite with the positive electrode, the current will continue to flow though the cell employs elementary substances for its electrodes and has no depolarizer in the ordinary sense of the word. A couple, as for example $Zn / H_2SO_4 / As$, employs very cheap materials, but it gives only about seven-tenths of a volt and many other objections prevent this combination from being of much practical use. The solid elements, such as sulphur or iodine, which will unite with the positive ions, are non-conductors, hence it becomes necessary to introduce into the circuit about a negative electrode of good conductivity a strongly negative element, which will unite with the positive ions and remove them as fast as formed.

Now, whatever form of battery may be adopted, there are certain general principles applicable to each of these three essential parts of a cell, viz: the electrodes, the electrolyte and the substance which serves for the negative depolarizer, which must be taken account of in order to make the apparatus efficient.

The Electrodes.—It is difficult to conceive a case in which it would be preferable to have a given amount of energy in a large, rather than in a small space, hence, as electrical energy is the product of current and electro-motive force, it becomes desirable that the cell should have as high an electro-motive force as is consistent with other considerations. When all the elements are excluded, which are more costly than silver and those which are non-conductors of electricity, we have only the following list to choose from:

Potassium,	Tin,	Bismuth,
Sodium,	Lead,	Mercury,
Magnesium,	Iron,	Nickel,
Zinc,	Cobalt,	Platinum,
Cadmium,	Copper,	Arsenic,
Aluminum,	Antimony,	Carbon.

The Positive Electrode.—The first three of these elements, together with their zinc alloys, cannot be used in electrolytes which contain any water, as they almost universally do, because their affinity for oxygen is stronger than that of hydrogen and consequently the water is decomposed with a consumption of the electrode and with evolution of hydrogen gas. Cadmium, and the metals which follow it, give a lower electro-motive force than zinc and are not cheap enough as yet to make them more economical than zinc. Iron has been used, but it has disadvantages besides its low electro-motive force, such as the formation upon its surface of an insoluble and non-conducting film which runs up the resistance of the cell. Thus zinc, considering its cleanliness, cheapness and high potential, appears to be the best metal to employ for the positive electrode. Amalgamating it diminishes local action and slightly raises its electro-motive force. It may be alloyed with advantage only where fine adjustments of electromotive force are sought, as might be the case in cells designed for standards of electro-motive force.

The Negative Electrode.—Much greater opportunity is offered for improvements in the negative electrode, both in respect to material and form. Negative electrodes may be divided into (1) those which are depolarized by an element not chemically united with the electrode; (2) those in which the depolarizing element is chemically united with the electrode, and (3) those which depolarize themselves chemically, as in the single case of arsenic, or mechanically, as by the exposure of a large extent of surface.

If the first class is used, then the following considerations must determine its material; the lower its potential the better. But if the depolarizer that is used is reduced by the action of the current to a metal which is deposited upon the electrode, then the electrode must have exactly the same potential as the reduced metal. Otherwise wasteful local action may take place, for a couple will be formed between the reduced metal, which is at one potential, and the electrode, which is at another. For example, with copper oxide

for a depolarizer, copper and not carbon should be used for the negative electrode.*

When, on the other hand, the depolarizer is an element, or a compound which is reduced to an inert material, such as PbO_2 reduced to PbO or Pb_2O_3, carbon makes by far the best electrode. It is cheap, nearly as negative as platinum, and, as we shall see later, can be made to serve the purpose of a porous cup as well as electrode.

The second class of negative electrodes, viz: those in which the depolarizing element is chemically united with the electrode, as is the case in the chloride of silver cell, is better discussed under depolarizers. The third class can at the best only be of service in open-circuit cells and will not be considered here.

The form given to the electrode is often quite as important as its material, especially when carbon is used. Most of the solid compounds employed as depolarizers have a high resistance, and all the elements which will serve the purpose are by themselves non-conductors (arsenic excepted), hence, if the carbon electrode is embedded in such a depolarizer and exposes but a small surface, the cell will have a high internal resistance and much of the electrical energy will be unavailable, as it will spend itself in heat within the cell. This is the way cells are often constructed, viz: with an electrode surrounded with a depolarizer of low conductivity. Liquid depolarizers, excluding the liquid element bromine, are not open to this objection, and hence the high efficiency of the Bunsen element, the gravity cell and others of that class. The best form to give the carbon electrode, for overcoming the internal resistance which results from using depolarizers of low conductivity, will be more clearly understood after a discussion of the depolarizing elements.

The Electrolyte.—The qualities, physical and chemical, which place a substance in the third class and make it an electrolyte, are so numerous that they can only be briefly

* Since the above was written I have made experiments which show that salts of mercury and carbon can be used together without any appreciable local action taking place. E. F. N.

mentioned here. Those interested are referred to "Meyer's Modern Theory of Chemistry," 1888 edition, page 532.

In general, no substance is an electrolyte which does not contain one or more of the six elements, S, O, Fl, Cl, Br and I. No substance will act as an electrolyte unless its particles are mobile and hence crystalline salts and solids in order to act as such must be either fused or dissolved in a liquid. Glass, for example, when fused becomes a very good electrolyte. Though pure water, alcohol and ether are non-conductors, the first becomes a very good one when mixed with certain substances, and the last two also become conductors when some salts are dissolved in them.

All electrolytes decrease in resistance with increase in temperature, and this makes one of the tests of the class in which to place a substance. Generally speaking, a dilute solution has a lower resistance than a concentrated one. Acid and alkali electrolytes give, as a rule, higher electro-motive forces than salts, but they are open to the objection of being liable to consume the positive electrode, which means that some of the energy stored up in the cell is given out in local heat instead of electricity. As a rule salts are better adapted to hermetically sealed cells, and acids or alkalies to open cells. If a salt is used, it should usually be a salt of the metal employed for the positive electrode with an acid radical the same as the active depolarizing element, for after the cell has been in action such a salt is always formed, and if other salts are present there is a liability that double salts may be produced, which will increase the resistance of the cell, or at least make complicated what might otherwise be simple. Thus in a zinc carbon couple, with bromine for a depolarizer, zinc bromide would be better to use than magnesium chloride. This is not, however, an inflexible rule to follow, for special cases may require special salts. The relations of the different excitants and their degrees of concentration to the electro-motive force obtainable with different combinations of electrodes has been fully worked out by investigators, and the results of the same are well presented in Tommasi's "Traité des Piles Électrique," which work, by the way, is one of the best records of what has

already been done in the practical construction of galvanic batteries.

It may be observed here, that as water is almost always present in the electrolyte, its hydrogen is deposited upon the negative electrode and causes the polarization. This is *always* true where the excitant salt is an oxygen salt of an alkali or alkaline earth metal, and generally so with other salts. This is due to a secondary action which takes place. If, for example, a salt of a positive metal like sodium is employed, when the metal is separated from the acid radical it at once decomposes the water and frees its hydrogen, the metal itself forming a hydroxide with the remaining portion of the decomposed molecule of water, thus

$$Zn_x + 2\ NaCl + 2\ H_2O + C = Zn_{x-1} + ZnCl_2 + 2\,NaOH + H_2 + C,$$

or

$$Zn_x + 2\ KOH + 2\ H_2O + C = Zn_{x-1} + Zn\,(OH)_2 + 2\ KOH + H_2 + C.$$

In fused electrolytes, where no water is present, this action, of course, cannot take place.

A further discussion of electrolytes would be more interesting from a scientific than from a practical standpoint, for they have never given trouble in the actual construction of an efficient battery. The chief thing that has to be taken note of is that the excitant is not of a kind or concentration to dissolve any part of the cell and produce local action. This is the reason that KOH cannot be used with advantage in a silver chloride cell, though the electro-motive force is much greater than with NH_4Cl, which is usually employed.

The Depolarizer for the Negative Electrode.—As the negative electrode is polarized by the formation upon it of hydrogen, it can only be chemically depolarized by such substances as will unite with nascent hydrogen. Now, whatever compound is used, the depolarizing is actually done by one of these seven elements, As, S, O, Fl, Cl, Br or I, or one or more of these in combination. Theoretically, some other elements belonging to the group of non- or

semi-metals will unite with nascent H, but their affinities for H are weak and practically could never with advantage be used. Arsenic and sulphur also have weak affinities, giving under the most advantageous circumstances less than a volt and generally less than half a volt. Fluorine is far too powerful to be used, either free or in combination. So, practically, a battery always makes use of O, Cl, Br or I for its negative depolarizer, though these may often act in a combined state as in the case of the acid radical SO_4. As the depolarizing is actually done by one of these four elements or two of them in union, it is obvious that the other element or elements with which they may be combined are so much inert material which play no part in the production of the current, and usually only act to clog up the cell, increase its internal resistance and add to the total bulk occupied by the materials. Hence, the theoretically perfect cell would employ electrodes at opposite ends of the potential scale, and have the negative electrode depolarized with the most negative free element. The parts would be so adjusted that all would be finally consumed at the same time, and the cell go to pieces like Dr. Holmes' "One Hoss Shay." There are certain difficulties connected with the use of free elements as depolarizers, which have led to the adoption of their compounds instead. In the first place, any element or compound which will give up an element capable of uniting actively with hydrogen, and hence serve the purpose of a depolarizer, will also attack the positive electrode of the cell. Therefore, the depolarizer must be kept separated from the positive metal. The difficulties of doing this are increased when the depolarizer is a liquid or gas. Oxygen and chlorine being gases, and both of them also but slightly soluble in water, are thus difficult to employ. Bromine and iodine in an unmixed or uncombined state have the disadvantage of being non-conductors and must be used in some special way if the current is to find free passage between the electrodes. The former, moreover, is an exceedingly penetrating liquid, which will diffuse with great rapidity through any porous partition which will permit the passage of the ions. Iodine, though much easier

to handle, and though nearly insoluble in pure water, is soluble in iodides of the metals and has heretofore only been used for experimental purposes. But whether an element or a compound be used for the depolarizer, it must be kept separated from the positive electrode. (1) This may be done by making the depolarizer an insoluble compound which will not tend to diffuse through the electrolyte. (2) By using a heavy oily liquid in the bottom of a cell which has no tendency to mingle with water. (3) Imperfectly by using porous cups or the gravity principle.

It is obvious that only cases one and two are applicable to small sealed portable cells, for if the depolarizer has a tendency to diffuse, no porous partition or gelatinous paste which will permit the passage of the ions will permanently arrest the action of diffusion, and a small dry cell made with a depolarizer which has a tendency to mix with the electrolyte will surely and inevitably carry on a local action resulting, in time, in its destruction. To be sure, this process is a matter of *degree* and may be greatly delayed and possibly kept back long enough to make a cell constructed upon this principle that is not invaluable. I may say here, however, that I experimented with small cells having a soluble depolarizer, which I attempted to keep in place by means of porous partitions and gelatinous pastes and found it to be practically impossible to make one that would last, upon open circuit, above a few months.

In respect to efficiency, a liquid depolarizer is much better than a solid depolarizer, and a gas best of all, for with solid substances the exhausted particles cannot be replaced as in the case of liquids and gases. For this reason the compounds PbO_2, MnO_2 and others of similar qualities do not depolarize effectively, or if they do, at least cause a high resistance in the cell. There is an exception to this rule in the case of cells made on the principle of the silver chloride and copper oxide cells, in which the reduced metal is left in a spongy state which permits the hydrogen to be absorbed nto its mass until it comes in contact with the still unreduced oxide or chloride.

Of the free elements bromine, while being one of the

cheapest is a very powerful depolarizer, giving with the combination $Zn / MgCl_2 / Br / C$, 1·9 volts. It is comparatively easy to handle, and when dissolved in CS_2 loses largely its fuming nature and if properly used does not lose its depolarizing properties. Some experiments made with this element showed that the carbon electrode could be made to serve the double purpose of electrode and porous cup. This was accomplished by taking a piece of an ordinary electric light carbon and boring a three-sixteenth inch hole down the centre for a distance of two inches. This hole was filled with grains of carbon, and free bromine was then poured into the hole. The hole was stopped with a carbon plug and connection made with a platinum wire. Such an electrode, ½ inch in diameter and 2 inches long, was placed in the centre of a five-ounce beaker containing a sheet of zinc for the positive electrode and with an excitant of KOH. This arrangement gave over two volts and three and one-fourth ampères as read upon a low resistance ampèremeter. Such a high efficiency was of short duration, as the bromine soon became exhausted, but the experiment goes to show that use may be made of non-conducting liquids for depolarizers when applied in this way. If porous cups could be dispensed with and the free elements O, Cl, Br or I in solution used in some such manner as the above, a very high efficiency might be attained.

I do not attempt to give details at this time about the construction of cells which make use of the free elements, but merely wish to point out the direction in which I believe increased efficiency in the production of galvanic electricity must be sought.

The difficulties in finding a suitable depolarizer for an hermetically sealed transportable cell are much greater than for an open battery which remains stationary. The sealed closed circuit cells now upon the market, which are good for anything, use a silver salt, which, under the most perfect conditions, will make a horse-power cost 119 times as much as it can be obtained for with free bromine, or five and one-half times as much as with free iodine. This observation is made, however, on the assumption that the silver used is

not recovered. As above stated, the depolarizer must be a solid, or at least of an oily nature, so that it will not diffuse through the electrolyte. If the salt of any metal is used which is reduced by the action of the hydrogen to the metal a potential of not over one and one-half volts can possibly be obtained (unless the rarer metals, such as osmium are made use of), and the cells that give that potential have some serious defects. If, on the other hand, an oxide like PbO_2 is used, which is not reduced to the metal, a higher electromotive force is possible, but the resistance of such a cell is quite sure to be high. Moreover, the list of insoluble depolarizers which will give an electro-motive force of over a volt is not long. Among the free elements, oxygen and chlorine, being gases, cannot be used. Bromine and iodine, however, may be, and it is these elements that are employed in the new cells to be described.

Non-essential Parts of Cells.—Besides the three essential features of every battery, viz: electrodes, electrolyte and depolarizer, there are certain other parts often required that deserve a few words.

The case for a cell is usually made of glass, but often zinc, copper or carbon are employed, and serve for one of the electrodes of the cell. If this arrangement is adopted and several cells are used together, they must be insulated from one another, so that economy in space is not necessarily gained. This plan is usually adopted to obtain surface and so reduce the resistance of the cell.

In all so-called dry cells the electrolyte is used in the form of a semi-liquid paste. As this paste is usually employed, it merely serves the purpose of holding the contents of the cell in a more or less rigid condition, by which means the battery is made more readily transportable than it would be if it contained a liquid free to move about. But the paste in a hermetically sealed cell can be made to serve a much more important function. Where the product of the union of the hydrogen with the depolarizing element is an acid, this acid must be neutralized, in order to prevent its action upon the zinc and the consequent formation of a gas. This is best accomplished by the use of a paste which consists of some

basic material. All organic substances, like starch or the hydrate of silica, which are often used as pastes, are non-basic and will not serve the purpose of neutralizing an acid, and in a small cell are of little value. Any cell which uses as its depolarizer a salt with a haloid acid radical, should therefore make use of some such product as MgO or ZnO if gassing is to be prevented. The neutralizing action of the paste which takes place may be shown thus:

$$ZnO + 2\ HBr = H_2O + ZnBr_2$$

or

$$Mg\,(OH)_2 + 2\ HCl = MgCl_2 + 2H_2O.$$

The objection may be raised to this view of the function performed by a paste consisting of a basic salt, that the acids formed by the action of the cell are exactly neutralized by a corresponding amount of alkali supposed to be formed at the same time, and hence the basic salt in the paste is superfluous. If we examine the following equations, which are supposed to represent the normal action of a $Zn_1/NH_4Cl_1/AgCl$ cell, the above objection would appear to be valid, thus:

$$Zn_x + 2\ NH_4\,Cl + 2\ H_2O + 2\ AgCl =$$
$$Zn_{x-1} + ZnCl_2 + 2\ NH_4OH + 2\ HCl + Ag$$

and then

$$NH_4OH + HCl = NH_4Cl + H_2O$$

and so no acid remains to be neutralized. This normal action, however, does not in reality take place, especially when the cell is worked hard. It is probably very much more complicated and is a thing very difficult to investigate. Practical experiments were tried, using a basic paste on the assumption that acid is formed in the cell in excess of an alkali, and is the cause of the hydrogen gas which is certainly produced in considerable quantity and that this paste would thus prevent gassing by neutralizing the excess of acid. The assumption was evidently correct, as numerous trials made of such a paste was found to prevent the gassing not only in the silver chloride cell, but in several other types having depolarizers containing one or more members of the hydrogen group.

The same objection is open to a paste that applies to solid depolarizers, viz: they do not allow diffusion of exciting liquids to take place as freely as it would in a liquid electrolyte. This objection, however, is proved by experiment to be much less than would be supposed. The resistance, moreover, caused by the use of a paste, if properly made, is insignificant.

Porous Partitions.—A full discussion of porous partitions and terminals is too special for the limits of this article, for each style of cell requires some particular device. If the terminals are in contact with the electrolyte they must, of course, be of the same potential, not necessarily of the same material, as the electrode to which they are attached. Thus, a platinum wire fastened to carbon will cause no appreciable local action. As stated above, the best results will be obtained when the carbon electrodes are so constructed that they will serve a double function of porous cup and electrode. In all cases a porous cup should be avoided where it is possible, for it is so much dead resistance in the cell.

The Seal.—The seal for a small dry cell is one of its most important parts and one not so very easy to construct well. It is astonishing what deterioration and changes time will work upon a battery. In fact, the time test for a battery, as for most things, is an extremely important one. "Will it last?" is the pertinent question, and the way this must be answered depends not a little upon the security of the seal. A warning, however, is easier to give than a remedy, as the many patents taken out for seals alone will go to prove. The expansions and contractions that take place with changes of temperature are almost certain, sooner or later, to produce an opening through which the contents of the cell will creep and cause its final destruction, unless the seal be well constructed. The neophyte inventor cannot give too much attention to this apparently insignificant feature of a closed battery.

Secondary cells have largely taken the place of primary batteries which are designed to supply much current, but the demand for small portable cells has been rapidly increas-

ing and nothing is likely to be invented which can replace them. Such cells are required by the physician to run his induction coils, and something of the sort is an absolute necessity for use in Wheatstone bridges and portable testing sets. Considering the very extensive demand for a small, compact and efficient dry battery, it is very surprising that the market is not better supplied. There are only two kinds now offered for sale which have any value whatever. They are both very expensive and must ever remain so, as they employ a silver salt for the depolarizer, and their electro-motive force, furthermore, is very low. Now, for the testing of resistance, especially high resistances, a high electro-motive force is required in order to make close measurements. If the resistance of the total circuit is great as compared with the internal resistance of the battery, the deflections of the galvanometer before a balance is obtained in the bridge are practically proportional to the total electro-motive force of the batteries. Hence the number of batteries required is inversely proportional to their electro-motive force. For testing work then, a cell with a volt and a half is just fifty per cent. better than a one volt cell. Cells employing a silver salt give at the most only 1·13 volts and average but about nine-tenths of a volt. A high electro-motive force is not the only requisite. A cell should even for test work have less than forty ohms internal resistance and for the running of induction coils the lower its internal resistance the better. Long life on open or closed circuit is also a desirable feature, for replacements are both expensive and annoying. But what is far worse than a gradual deterioration, which is seen and can be calculated for, is a sudden going to pieces of the cell, which may leave a man helpless in the midst of pressing work. This is a serious fault of the silver chloride battery, for they often generate a gas which sooner or later causes them very unexpectedly to explode.

I desire to bring to your notice to-night some new dry cells, one type of which is designed for testing use and another for running induction coils. They are the final result arrived at after some months spent in experiments at the electrical laboratory of Queen & Co.

The points brought out in this paper were kept well in mind in the construction of these cells and after many changes in the details the following forms of cells were finally settled upon:

The "Test" Cell.—As portability is a great desideratum with test cells and as only a very small current is taken from them, the cell designed for this purpose was reduced

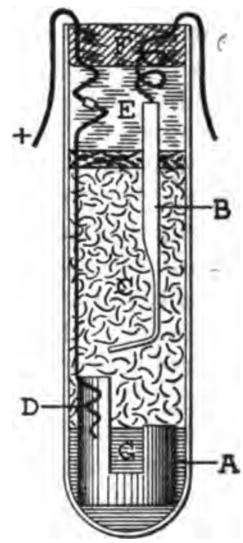


FIG. 1.—Small iodine test cell, 2 inches long by ½ inch in diameter.

A = carbon electrode.

B = zinc electrode.

C = paste made of $AlCl_3 + ZnO + MnO_2 + H_2O$.

D = fine platinum wire moulded into carbon electrode.

E = viscous seal.

F = plaster Paris seal.

G = depolarizer, which may be I_2S_2 giving 1·35 volts, or $HgO + I$ giving 1·65 volts initially with an average of 1·4 volts.

in size very much from those usually used. They are made in what are called round bottom specimen tubes. The smallest size constructed have a length of two inches with an outside diameter of only half an inch (see *Fig. 1*). In spite of this small size the average resistance of these cells when first made up is not greater than twenty-five or thirty ohms, and after the cell has been put in use the resistance grad-

ually falls a few ohms. The electro-motive force of this cell when the depolarizer is sulphur iodide (I_2S_2) is 1·45 volts. They will thus average 1·4 volts. The silver chloride cell with a case of paper and paraffine upon it, which is required to keep the glass from flying when they explode, measures $2\frac{3}{4}$ inches in length by $\frac{7}{8}$ of an inch in diameter; being round they thus have a total volume of 1·62 cubic inches. One of the cells here described, which I may call the iodine cell, iodine being the active depolarizer, has but four cubic inches or less than one-fourth the volume of the silver chloride cell; or 100 silver chloride cells would require seventy-six square inches of space against twenty-five required by an iodine cell. Further, as the electro-motive force of an iodine cell is about 1·4 as against ·9 of a volt for a silver chloride, we have

$$\tfrac{1}{3} \times \frac{\cdot 9}{1\cdot 4} = \tfrac{3}{14}$$

or practically one-fifth the space is required to obtain a given electro-motive force as is needed if silver chloride cells are used. If this decrease in size is at the expense of a corresponding decrease in efficiency, it might not be advisable, but such is not the case, for these cells will give, with such external resistances as are ordinarily used in test work, fully as much current as a silver chloride cell. Further, the total output of these cells is about ·2 to ·3 of an ampère hour. That of a silver chloride is ·6 to ·7; thus while the output of an iodine cell is one-third that of a silver chloride, the volume is only one-fourth as great. Carbon and zinc electrodes are employed, and the low resistance of these cells is largely due to a peculiar shape given to the carbon electrode (see *A*, *Fig. 1*). The depolarizer consists of I_2S_2, sulphur iodide, which is the only binary compound of iodine insoluble in water, with the exception of a mercury and silver salt, neither of which give a high electro-motive force. This depolarizer is put both below and above the carbon electrode, being filled in as high as the top of the lower prong of the carbon electrode (see *Fig. 1*). Now by the action of the cell a very little zinc iodide is formed, which renders the iodine in the depolarizer slightly soluble. The prongs of

the carbon, which is of a fairly porous quality, act like a wick to soak up this soluble portion and thus the electrode is kept perfectly depolarized at the exposed ends. The depolarizer, which is ground into a powder, has, moreover, a little of the paste, which is used in the cell, mixed with it, and thus a fair degree of conductivity is given to the whole mass. These two facts together cause the cell to have a very low internal resistance. Three parts by weight of iodine are used and one part of sulphur, and, as the iodine is very loosely held by the sulphur, we can say that the iodine is practically used in a free state. These cells have also been made using a depolarizer which consists of a chemical compound of HgO, mercury oxide, and iodine, with a slight excess of iodine. The formula of this compound is thought to be Hg_2O, IO_4, HgO, IO_4. This depolarizer gives an initial electro-motive force of 1·65 volts, which, however, falls in time to about 1·4 volts, where it remains nearly constant until the cell is used up. This form of depolarizer is also quite insoluble in the electrolyte used and seems to have a lower resistance when combined with a little of the paste used in the cell than the sulphur iodide. This compound does not become reduced to the metal until the cell is nearly exhausted, so there is no local action which takes place, as might be expected, between reduced globules of mercury and the carbon electrode. Tests are now being made to decide between the relative advantages of these two depolarizers. Queen & Co. have been using both types of cells for some months in adjusting all their resistance coils, and enough has already been learned, through a practical and hard test about each, to make it quite certain that they are both excellently adapted to the use to which they are put.

The paste in these cells consists of zinc oxide and aluminum chloride and water. This combination, by the formation of some aluminum hydroxide and zinc chloride, makes a smooth gelatinous paste of any desired consistency and has the important property of neutralizing the hydriodic acid that is formed in the cell, so that these batteries are quite free from gassing and will never explode. The pro-

ducts of the cell, when the circuit is closed, simply change form until the cell is used up. The following equations express the normal actions that probably take place:

(I) $Zn_x + 2\ AlCl_3 + 6\ H_2O + 3\ ZnO + [X\ (ZnCl_2)] + [X\ (Al\ (OH)_3)] + 3\ I_2S_2 + C = Zn_{x-s} + 3\ ZnCl_2 + 2\ Al\ (OH)_3 + 6\ HI + 3\ ZnO + [X\ (ZnCl_2)] + [X\ (Al\ (OH)_3)] + 3\ S_2 + C.$

(II) $6\ HI + 3\ ZnO = 3\ H_2O + 3\ ZnI_2.$

Some zinc chloride may also take part in the action when the cell is first started and later some zinc iodide. Some of the HI is also probably neutralized thus:

$$Al\ (OH)_3 + 3\ HI = AlI_3 + 3\ H_2O.$$

$AlCl_3$ is used in preference to salts of the alkali metals, for it has no dissolving action whatever on either of the depolarizers above described, which many other salts dissolve to a greater or less extent. Powdered charcoal, or preferably manganese dioxide, is also added to the paste, partly to thicken it and chiefly to improve the appearance of the cell. The fact that the zinc iodide, formed after the cell has been in action, dissolves the depolarizer to a certain extent, may be thought to be a disadvantage, but it is rather an advantage, for while it reduces the resistance of the cell, it also makes the depolarizer much more efficient in its action than it would be if absolutely insoluble. In fact, if a depolarizer is perfectly insoluble, its action must be tardy, and a cell using such will not only soon polarize, but usually have a very high resistance.

The seal in these cells is made as follows (see *Fig. 1*): The zinc electrode is held in place by a cork, over this is poured a hot mixture of gutta-percha, pitch and resin oil. This viscous material is then made secure by having poured over it a layer of the same mixture with an equal part of plaster Paris mixed through it. The terminals are both brought out of the top of the cell (see *Fig. 1*), one being of platinoid and the other of copper wire, so that the poles may be distinguished from each other.

Some careful tests were made of the life of different cells, usually by determining the total number of coulombs that they could furnish. This test was conducted by running the cells connected in series through a copper voltameter until they were completely exhausted. Some resistance was usually placed in the circuit to prevent too rapid action. The life of a Barrett silver chloride cell tested in this way proved to be 2,473 coulombs or nearly $\frac{68}{100}$ of an ampère hour. The

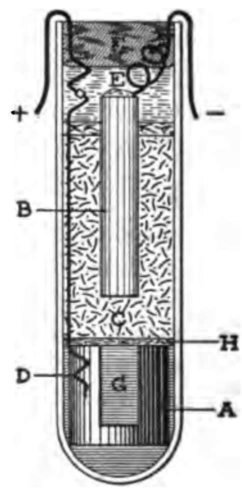


FIG. 2.—Large iodine test cell.

A = carbon electrode shown in perspective in *Fig. 3*.
B = zinc electrode.
C = paste, same as in other cells.
D = platinum fine wire.
E = viscous seal.
F = plaster Paris seal.
G = depolorizer, either I_2S_2 or $HgO + I$.
H = partition of asbestos cloth.

average total current supplied by one of the smallest size iodine cells described above (see *Fig. 1*), in which the depolarizer was sulphur iodide, was ·21 of an ampère hour. This, considering the small size of the cell, is a very high efficiency and it might be increased somewhat if desired by using a larger proportion of the depolarizer. The iodine and mercury oxide depolarizer gives even a higher efficiency than this. A similar test was made upon a larger size iodine cell, which

had a volume of 1·1 cubic inch, and the form slightly modified, as shown in *Figs. 2* and *3*. This furnished 2,295 coulombs or ·64 of an ampère hour. As these cells are only intended for test work very little current is taken from them. Assuming that the average resistance used in the entire circuit of a resistance set is 1,000 ohms, and that forty volts are used and that the duration of each closure of the key is one second, 17,500 taps would be required to exhaust one of the smallest cells and 57,375 to exhaust one of the larger ones. Thus for the purpose to which these cells are adapted their life is very long.

Of course, this same combination of materials might be used in cells of various forms and any size. A cell, constructed as shown in *Fig. 2*, which is $\frac{5}{8}$ x $2\frac{1}{2}$ inches, will have under thirty ohms internal resistance and will furnish

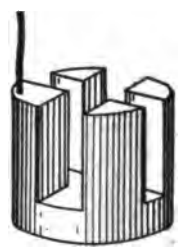


FIG. 3.—Perspective view of carbon electrode used in larger form of test cell.

through fourteen ohms external resistence about thirty to forty milliampères; so this style of cell may also be used with advantage where current rather than electro-motive force is required. Other forms, however, were devised for this purpose. *Fig. 4* shows a cell with a square case, $1\frac{1}{8}$ x $2\frac{3}{4}$ inches, which is especially adapted for running physicians' induction coils. The depolarizer, which may be either I_2S_2 or $HgO + I$, is placed in the partitions of a box-like carbon electrode, the open side of which is placed against the side of the glass case. The carbon electrode is thus seen to serve also the purpose of a porous cup. This general principle of having the depolarizer behind or inside of a porous carbon electrode, so that the current does not have to pass through a substance of high resistance, is one which seems capable of valuable developments. Experiments are now

being continued along this line aiming towards the construction of a large powerful battery for cautery work, running of motors and other purposes where great efficiency combined with transportability is required, and it is hoped that results will soon be forthcoming.

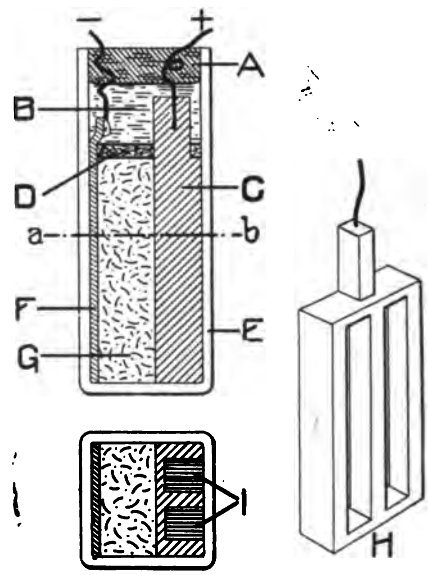


FIG. 4.—Iodine cell adapted for large current output.

A = plaster Paris or cement seal.
B = viscous seal.
C = carbon electrode (view of edge).
D = cork to hold electrodes in place.
E = containing case of glass.
F = zinc electrode (view of edge).
G = paste (same as in test cells).
H = perspective view of porous carbon electrode.
I = depolarizer, either I_2S_2 or $HgO + I$.

Some very exhaustive experiments were made, using free bromine for a depolarizer. But this in an unmixed or uncombined state had to be finally abandoned, as the bromine diffused through the electrolyte and caused the cell, whether kept on open or closed circuit, to give out in about a month. The device was finally adopted of dissolv-

ing the bromine in carbon disulphide. This practically prevents diffusion of the bromine, but does not seem to affect its qualities as a depolarizer when used with a porous carbon electrode like the one described and shown in *Fig. 3*. The combination gives about 1·8 volts. It is hoped that these cells are free from defects, but the important test of time must be given to them before this can be positively asserted.

The complete record of the action of a battery is given by curves which represent their polarization, recovery, internal resistance, terminal potential difference and current. The method adopted for obtaining these curves is fully described in Prof. H. S. Carhart's work on primary batteries.

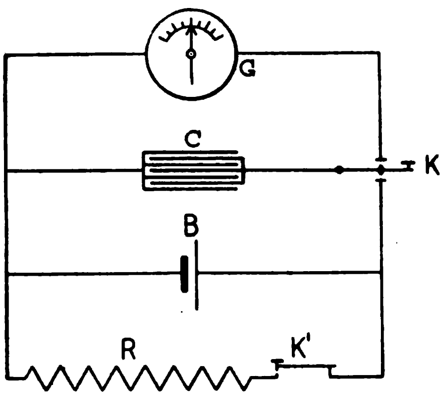


FIG. 5.

It may be called the condenser method and briefly stated is as follows:

In the diagram, *Fig. 5*, G is a ballistic galvanometer, C a condenser, B a cell, R a resistance, the fall of potential over which is to be measured; K' a key to put this resistance in circuit with the battery B, and K a double key for charging the condenser and discharging it through the galvanometer.

The condenser is first charged (K' being open) by means of a Carhart-Clark standard cell, then discharged and the galvanometer deflection read by means of a telescope and scale. The standard is then replaced by the battery to be tested. With K' open, the condenser is charged and discharged as before. Then K' is closed and after an interval

of one minute the condenser is again charged and discharged. K' is now kept closed for an hour, except at intervals of two minutes, when it is opened just long enough to charge and discharge the condenser, and readings are taken which give the potential of the cell on open circuit. The condenser is also charged and discharged, K' being kept closed, at intervals alternating with the open circuit readings. At the end of the hour K' is opened permanently and open circuit readings are taken at intervals of one minute or longer. In this way the recovery curve is obtained.

The deflection of the standard and its electro-motive force being known, the electro-motive forces corresponding to the other deflections are calculated from a simple proportion or more easily read off from a straight line curve, which is readily drawn.

The internal resistance of the cell at any moment during the hour is obtained as follows: Call the electro-motive force of the open circuit readings at any moment E; that of the closed circuit reading at the same moment, which is the fall of the potential over the resistance, R, E', then, if r is the internal resistance sought, we can make the following equations: There is a total potential of E, there is a fall of potential over the external resistance E'. Therefore, there must be a fall of potenial $E - E'$ over the internal resistance, hence $r : R :: E - E' : E$ or

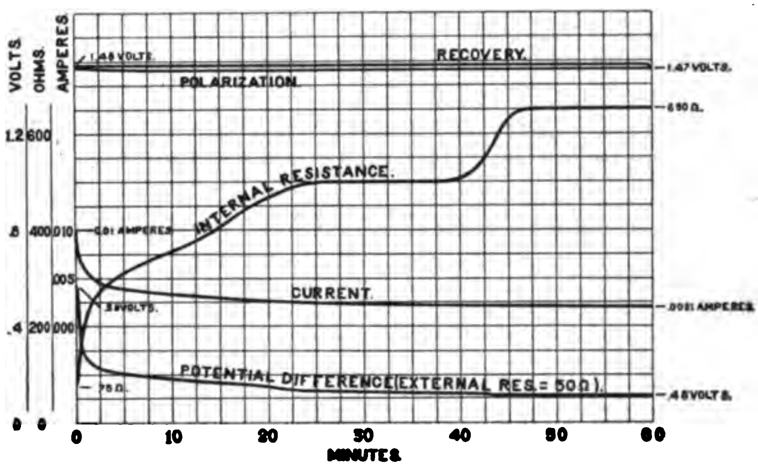
$$r = \frac{E - E'}{E'} R$$

After the polarization curve given by the different electromotive forces called E, and the terminal potential difference curve given by the electro-motive forces called E' are plotted, then the data for solving the equations giving the points for the internal resistance curves can be read off on the ordinates directly. The current flowing at any time is, simply,

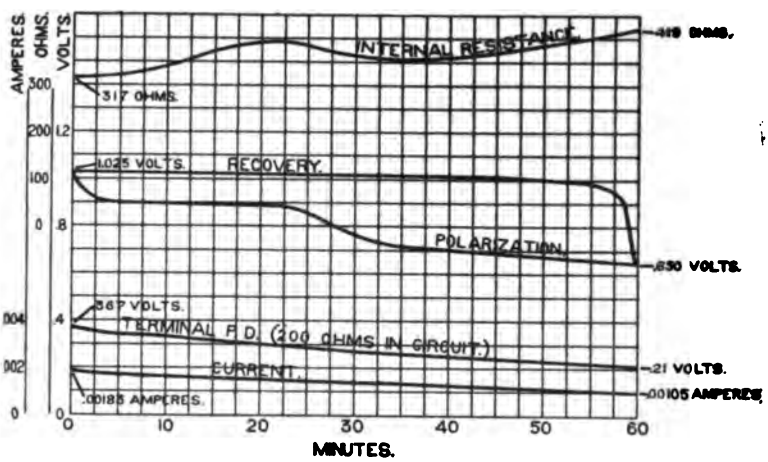
$$C = \frac{E'}{R}$$

If in addition to this test a battery is run completely out through a voltameter, and the number of coulombs that it

will furnish be calculated, and, if further, after being used some it is laid away for a few months to test if any destructive local action goes on, then, if all these tests are



CURVES No. 1.—Curves of a $Zn / MgCl_2 / Hg_2SO_4 / Hg$ cell. Size, 2 x ¾ ins.



CURVES No. 2.—Curves of a $Zn / ZnCl_2 / CuO / Cu$ cell.

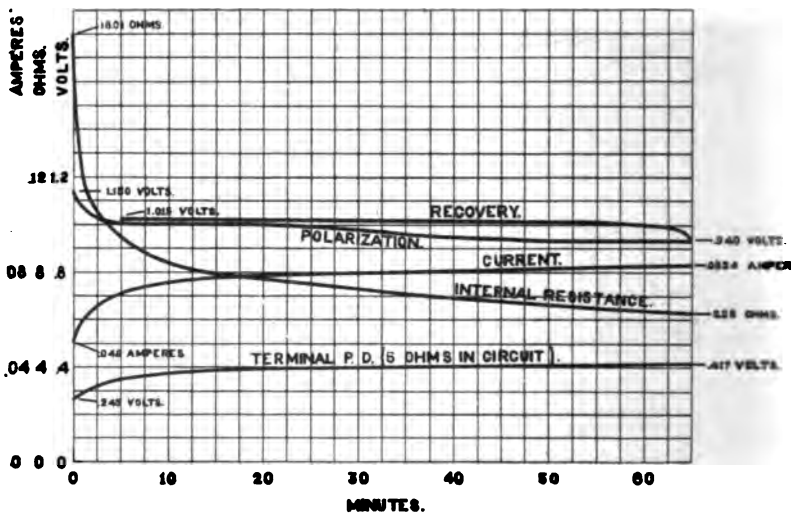
favorable, the battery may be pronounced a good one, and not with certainty before.

There are very few of the "wonderful" dry cells advertised which will bear such an exposure as the above tests will give them, and unless the manufacturers of cells claimed

to be perfection are willing to submit their goods to such tests their honesty will at least bear examination.

The following curves of some dry cells made by various parties and characteristic of different types of depolarizers are given for reference. These cells do not differ much in size from the iodine cell shown in *Fig. 2*:

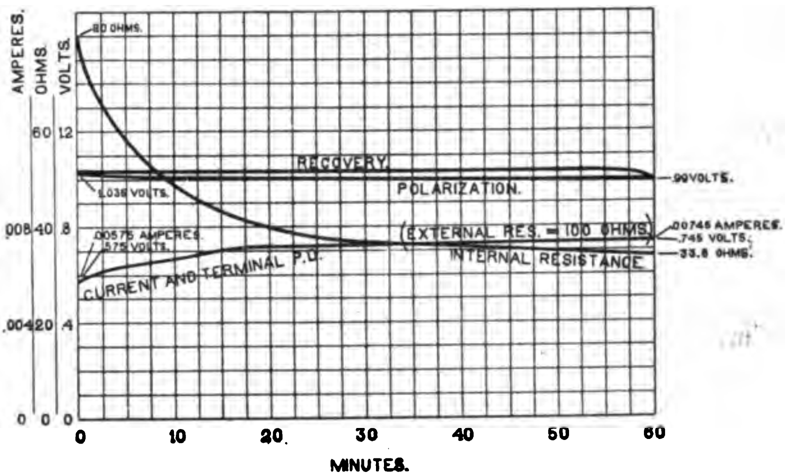
Curves No. 1 represent the action of a $Zn/MgCl_2/Hg_2SO_4/Hg$ cell constructed upon the same general plan as the iodine cell in *Fig. 2*. The Hg_2SO_4 is a solid depolarizer and the cell has a very high resistance, which runs up rapidly. The electro-motive force of this combination is the highest



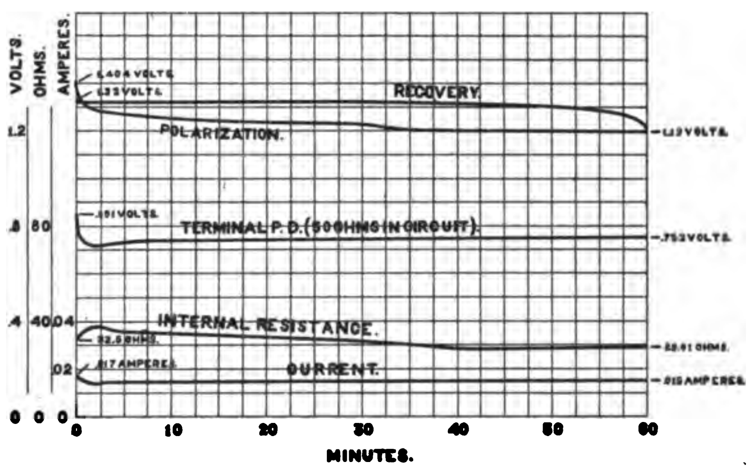
CURVES NO. 3.—Curves of the Barrett silver chloride cell.

that can be obtained in a closed cell in which a metal is used for the negative electrode, which is depolarized by a salt that is reduced to this metal, unless use be made of the rarer elements. Curves No. 2 are those of a cell with CuO for a depolarizer and a paste made of red oxide of iron. These cells also are valueless on account of their high resistance. They have also, considering the small amount of current taken from them, polarized very rapidly. Curves No. 3 are those of a Barrett silver chloride cell. The resistance of these cells rapidly falls as the silver chloride of poor conductivity becomes reduced to spongy silver of the

very best conductivity. The faults of this cell, such as gassing and local action, are not shown by the curves, but it is seen that the electro-motive force is on an average only a little



CURVES NO. 4.—Curves of the Stevenson silver chloride cell, same size as Barrett cell. Size of cell itself without protecting case is 2⅝ x ¾ inches.



CURVES NO. 5.—Curves of small iodine test cell. Size, 2 x ½ inches. Depolarizer, sulphur iodide (I_2S_2).

above nine-tenths of a volt. The curves of this cell, nevertheless, are very fine, for silver chloride contains a large percentage of the most active depolarizing element, combined

with the best known conductor. The cost of silver chloride, however, is a strong objection to its use. Curves No. 4 are those of a Stevenson silver chloride cell. The resistance of this cell is greater than that of the Barrett cell, but it has polarized less. The low resistance of the Barrett is due to the fact that the poorly conducting silver chloride is wrapped about with a fine silver wire. The Stevenson cell does not have this wire, which results in a higher resistance, but having no free silver surface the polarization is less.

Curves No. 5 are those of a small iodine cell, only 2 x ½ inches, with a depolarizer of I_2S_2. The resistance, it will be observed, decreases, though at the start it is far within the limits allowable for a test cell. The electro-motive force is also seen to drop. This is due to the exhaustion of the nearly insoluble iodine from the end of the carbon prong, but the recovery is very prompt, so that for testing work, where only a little current is taken at a time, the available electromotive force will be that shown by the end of the recovery curve.

For purposes where much steady current is required the size and form of these cells will be like that indicated in *Fig. 4*. Curves of this latter form have not yet been obtained, but several tests have been made by running them completely out on a milliampère meter and upon induction coils which have proved their very high efficiency. With HgO united to I their available electro-motive force is about 1·4 volts and their internal resistance between one and three ohms, and their total output greater than the silver chloride cells described.

The battery problem is not an electrical one merely. It is chiefly a chemical and mechanical question and one which a person with only an electrical knowledge can scarcely hope to undertake with success. There are many improvements yet to be made in primary cells, and those who take the work up should bear in mind that a good battery, like anything that is at all complicated, cannot be stumbled upon, but must be laboriously and logically studied out, and then proved by careful experimenting to be of sterling value.

PROCEEDINGS.

[*Stated meeting, held Tuesday, February 28, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, February 28, 1893.

Mr. Elmer G. Willyoung, President, in the chair.

Present, thirteen members and visitors.

The minutes of the previous meeting were read and approved.

The Treasurer reported the cash balance in the treasury, and presented bills for printing, etc., which were approved and ordered paid.

It was moved and carried that in future the annual volumes of the Section's Proceedings be sent to members of the Section, but to non-members only on the joint order of the President and Secretary.

Mr. Robert H. Laird was elected Secretary and Treasurer of the Section, for the unexpired term of Prof. L. F. Rondinella, resigned.

Mr. Geo. F. Stradling was unable to present his paper on "The Migration of the Ions," on account of illness, which prevented his attendance.

Mr. Carl Hering made some interesting remarks on "The Smashing Point of Incandescent Lamps," with blackboard illustrations. Taking the decreasing efficiency of a lamp into account, and the correspondingly increasing total expense per candle-power per hour, he showed from the results of Professor Thomas' tests of American lamps, that it would be most economical to renew the lamps after running them 400 or 500 hours. The subject was discussed by Messrs. Pike, Rondinella, Billberg, Winand and Willyoung and other interesting points in connection with incandescent lighting were brought out.

Mr. Carl Hering presented a list of all the electrical journals published in the English, French and German languages. Referred for publication.

Upon motion, the President appointed a committee, consisting of himself and Messrs. Hering and Pike, to arrange for the entertainment of members at the meetings of the Section.

Adjourned. L. F. RONDINELLA, *Secretary.*

PROCEEDINGS.

[*Stated meeting, held Tuesday, March 28, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 28, 1893.

MR. E. G. WILLYOUNG, President, in the chair.

The stated meeting of the Section held on this date, was called to order by President Willyoung, at 8.10 P.M.

Present, thirty-four members and visitors.

The minutes of the previous meeting were read and approved.

The Treasurer reported a cash balance of $59.92 in the treasury, and presented bills for printing amounting to $35.51, which were ordered paid.

On behalf of the special committee appointed at the last meeting for the entertainment of members at this meeting, Mr. C. W. Pike stated that arrangements had been made for an informal lunch to be held at Reisser's restaurant, at the close of the evening's exercises.

Upon suggestion by Dr. Wahl, the Secretary was instructed to send a list of associate, corresponding and honorary members of the Section to the Actuary of the Institute.

Owing to an engagement, Prof. Houston's paper, on "Chas. A. Coulomb and his Work," was given first place on the programme.

It was an interesting memoir, and evoked quite a discussion concerning the correctness of some of Coulomb's discoveries, as viewed in the light of present knowledge.

The paper was referred for publication.

"The Migration of the Ions," by Prof. Geo. F. Stradling, was a *résumé* of researches by Hittorf and Kohlrausch on the velocity of various ions in solutions of varying degrees of density. This was followed by a paper by Mr. C. Billberg, on "A Simple Method for Increasing the Output of Dynamos and Motors." This method is to use iron for the binding wire of the armature instead of non-magnetic alloys.

Mr. Carl Hering pointed out the fact that Dobrowlsky made use of an iron ring inside the pole pieces, which diminished the sparking and allowed the shifting of the brushes to the position of greatest difference of potential, thus increasing the output.

Mr. Winand pointed out the distinction between Dobrowlsky's method and that of Mr. Billberg.

It was moved that further discussion on the papers of Prof. Stradling and Mr. Billberg be postponed till the next meeting, and that the papers be printed and sent out as soon as possible.

The meeting then adjourned. R. H. LAIRD, *Secretary.*

THE MIGRATION OF THE IONS.

By George Flowers Stradling.

[Read at the stated meeting of the Electrical Section, March 28, 1893.]

For almost a century the passage of an electric current through an electrolyte has been attributed to direct transportation of the electricity by the ions resulting from the decomposition brought about by the current. The changes and improvements imparted to the crude theory of Grotthuss by Williamson and Clausius, and more recently by Svante Arrhenius, have not altered this explanation. Upon the startling, yet apparently correct, theory of Arrhenius, the reasoning which will subsequently be used might be based; but, as Grotthuss' simpler hypothesis lends itself more readily to explanation, it will be employed.

Suppose we are electrolyzing a dilute solution of sulphuric acid. The hydrogen goes with the current and appears at the kathode; the radical SO_4 moves against the current, and, but for secondary action, would appear at the anode. Each ion moves through the liquid, but with what velocity? Shall it be assumed that the velocity is the same for both ions? One thing that will go far toward determining the velocity is the friction of the moving atoms against their environment. As the hydrogen atom makes its way toward the kathode, it will come in contact with other hydrogen atoms and with the liquid in which the acid is dissolved, perhaps also with SO_4 groups moving in the opposite direction. The same thing is true of the other ion. Now, the two ions are, of course, quite different in nature, and the resistance which they will experience will, in general, be different. Hence, in general, their velocities will be different.

So much for the antecedent probabilities of the case. In order to put this reasoning to the test, it will be necessary to deduce results that must follow were the velocities the same, and others which must follow, if they are different, and then, by experiment, to determine which deductions are supported by facts.

Let the diagrams (*Fig. 1*) represent in a general way electrolysis upon the supposition that the ions move with equal velocities in opposite directions. *AB* represents an imaginary partition, so situated in the liquid that any changes in concentration arising at the electrodes will not affect the electrolyte in its vicinity. The positive and negative ions,

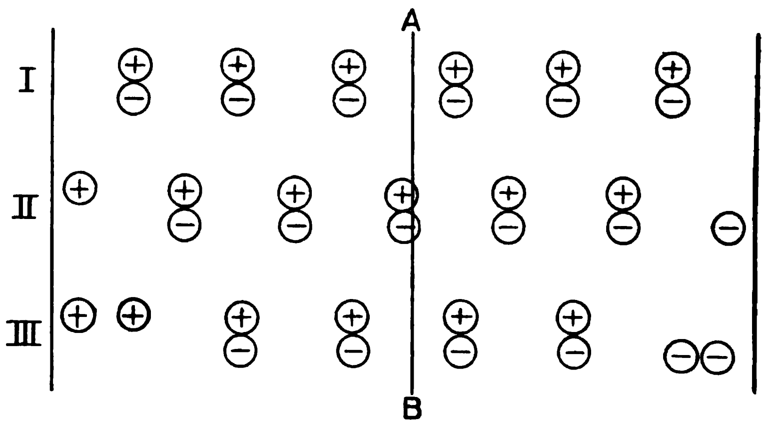


FIG. 1.

united in the molecules of the substance being electrolyzed, are represented by circles having + and — signs, respectively. *Diagram I* represents the position of the ions before the passage of the current. In *Diagram II*, the current has passed long enough to move each positive ion to the left and each negative one to the right, through an equal distance, that distance being just enough to cause the liberation at the electrodes of one atom of each ion. In *Diagram III*, two atoms of each ion are set free, and two molecules of the electrolytic substance have been broken up.

In *I*, there were three positive and three negative atoms on each side of the partition *AB*. In *III*, to the left of *AB* there are four positive atoms, and to the right four negative

ones. Thus the gain of positive atoms to the left equals the gain of negative ones to the right. If now the entire quantity of the positive ion to the left of *AB* be found, including both the amount in the liquid and that set free at the kathode, and the gain over the amount present before the passage of the current be compared with the amount liberated at the kathode, the ratio is seen to be one-half, which is the same for the negative ion to the right of *AB*. The determination of the amount of the two ions present in the liquid can be made by chemical analysis, and thus

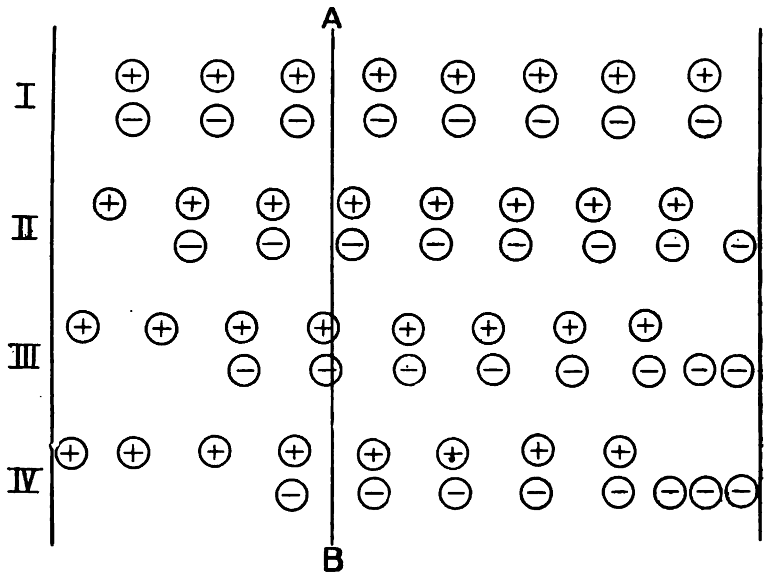


FIG. 2.

the tenability of the supposition of equal velocities be examined. If it is found that to the left of *AB* there is, after the passage of a current, a gain of the positive ion equal to one-half of the quantity set free at the kathode, and that the ratio holds true for the negative ion also, then, and only then, will it be shown that the ions have equal velocities.

In *Fig. 2* the positive ion moves to the left with but half the velocity with which the negative one moves to the right. *AB* has the same meaning as before; *I* represents

the conditions before the passage of the current; *II*, *III* and *IV* show the state after the electrolysis of one, two and three molecules. Before the passage of the current, there are three positive atoms to the left and five to the right of *AB*, and, of course, the same number of negative ones. After three molecules have been dissociated, we find four positive atoms to the left and seven negative ones to the right; a gain of one positive atom and of two negative atoms on the respective sides. It will be noticed that the gains are as 1 : 2, in the same ratio as the velocities. A little consideration will show that, in every case, no matter what the ratio of the velocities is, this will hold true. In general, if the velocities of anion and kation are as $p:q$, for every p anion atoms that cross *AB* in one direction, q kation atoms cross in the opposite direction; and, since the gain of each ion is produced by the transference from one side of *AB* to the other, the gains are as the velocities.

A knowledge of the number of positive and negative atoms in each of the two portions of liquid separated by the partition *AB* would render it possible to decide whether the ions do move with unequal velocities. Though chemical analysis gives no knowledge of the absolute number of the atoms, yet it will give with certainty the relation of the gains of kation and anion, and this is sufficient. Take the case where the velocities are unequal, and, as above represented, in the ratio 1 : 2. Three molecules are dissociated. Three positive atoms appear at the kathode, and, to the left of the partition, one more such atom is present than before the passage of the current. The gain is, therefore, one-third of the quantity set free. Two negative atoms are gained on the right side, two-thirds of the quantity set free. If, then, we know how much of the positive ion is present to the left of the partition at the beginning of the experiment, how much at the end, and how much is liberated or deposited at the kathode, the velocity of the positive ion is proportional to the amount gained divided by the amount liberated or deposited. In getting the amount present after the passage of the current, both that in the liquid and that set free at the kathode are to be taken into account.

The same procedure carried out for the anion, of course, gives a fraction to which its velocity is proportional, and the sum of this fraction and that obtained for the kation is unity. It is manifestly not necessary to carry out the analysis for both ions, for, having found one fraction, the other is found by subtracting the first from unity. For instance, if it is found that the gain of the kation to the left of the partition is two grammes, and the amount liberated is five grammes, then the velocity of the kation is as two-fifths, and the velocity of the anion as $1 - \frac{2}{5}$ or $\frac{3}{5}$. The velocities are here as $\frac{2}{5} : \frac{3}{5}$ or $2 : 3$.

Hittorf* applied the reasoning which has been given to the determination of the velocities of a good number of ions. To collect the liquid on one side of an imaginary partition for analysis is no easy matter, but he succeeded in doing this with great skill, and obtained results which show a remarkable agreement with each other.

The following is an example of how the relative velocities were found for $CuSO_4$.

	Grammes.
Quantity of Cu liberated at kathode, ...	·3161
Decrease of Cu in solution on kathode side, ...	·2288
Net gain of Cu, ...	·0873
Ratio of gain to deposit, ...	$\frac{873}{3161} = \cdot 276$

Hence, vel. of Cu : vel. of SO_4 :: 276 : 724.

A table of Hittorf's results is to be found in vol. ii, *Wiedemann's Electricität*, from which those below are taken:

Substance.	*H_2O to 1 Gramme. Substance.*	Velocities. *Kation.*	*Anion.*
NaCl, ...	3·47	·352	·648
	20·70	·366	·634
	104·76	·372	·628
	320·33	·383	·617
Na_2SO_4, ...	11·77	·359	·641
$NaNO_3$, ...	2·99	·400	·600
KCl, ...	4·84	·484	·516
K_2SO_4, ...	11·84	·500	·500
KNO_3, ...	4·62	·521	·479
HCl, ...	2·90	·661	·339

* *Vide Pogg. Ann.*, lxxxix, xcviii, ciii, civ and cvi.

Two changes might affect the relation of the velocity of the kation to that of the anion alteration of current strength and of concentration. Both were investigated by Hittorf. He found that the relative velocities are independent of the current strength.

For a solution of $CuSO_4$;

Intensity of Current.	*Velocity of Kation.*
113	·291
420	·285
958	·289

On the other hand, concentration does have a very decided influence. An instance of this may be seen in the case of NaCl, in the table given above. For $CuSO_4$ the following results were obtained:

	Velocity of Cu.
One part $CuSO_4$ to 6·35 H_2O.	·276
9·56	·288
18·08	·325
39·67	·355
76·88	·349
148·3	·362

There is, however, no reason to suppose that, in general, the effect of dilution would be to increase the velocity of the kation rather than that of the anion.

For twenty years after the publication of Hittorf's results upon the relative velocities of the ions, so far as the writer knows, no one made use of them in any way to get the absolute velocities. This was left for Friedrich Kohlrausch to accomplish.*

Think now of an atom of an ion moving in a dilute solution. Its friction is chiefly against the solvent, and but little against the other constituent of the salt in solution. It will then probably make but little difference what that other constituent is. The atom will probably move with a velocity not at all dependent upon the other atom from which it has been separated. In other words, it seems likely that in dilute solutions each ion moves with a velocity peculiar to itself and to the solvent, and not depending

* *Wied. Ann.*, vi, 160.

upon the salt from which it has come. Kohlrausch drew from his wide-reaching observations on the conductivity of dilute solutions data which show that such is really the case.

Suppose we have a portion of an electrolyte one centimetre long and one square centimetre in cross-section. Let its conductivity be k, the velocity of the kation be u, and of the anion v.

Let the cubic centimetre contain as much of the salt to be electrolyzed as would be formed by the union of that quantity of the positive ion which will convey m units of positive electricity to the kathode with the amount of the negative ion which will carry the same amount of negative electricity to the anode. One volt electro-motive force will be supposed to exist between the ends of the liquid column.

By Ohm's law—

$$C = \frac{E}{R} = E \cdot K, \text{ or as } E = 1, C = K. \qquad (1)$$

It is also possible to express the current strength in terms of u and v. There are m units of positive electricity moving toward the kathode with the velocity u, and an equal quantity of negative moving in the opposite direction with the velocity v. This is equivalent to m units of positive electricity moving to the kathode with the velocity $u + v$. In one second, then, $m\ (u + v)$ units of positive electricity would pass through any cross-section of the liquid column, and this is accordingly another expression for the current strength.

$$C = m\ (u + v) \qquad (2)$$

From (1) and (2) we get

$$K = m\ (u + v) \qquad (3)$$

From his experiments, Kohlrausch found the quantity by which m must be multiplied in order to get the conductivity. By comparison with (3) it is seen that this quantity must equal the sum of u and v. From Hittorf we get the ratios of u and v, and from Kohlrausch their sum, and from

the two relations the absolute values of u and v are readily obtained.

The following results, in which numbers proportional to u and v are given, show how near to the truth is the supposition that the velocity of an ion in a dilute solution is independent of the salt from which it is separated:

	From Chloride.	*Iodide.*	*Nitrate.*	*Acetate.*
K, ...	$u = 48$	51	46	47
Na, ...	$u = 31$	34	29	31
	Cl.	*I.*	NO_3.	$C_2H_3O_2$.
From potassium salts, . . .	$v = 50$	52	45	23
sodium salts, ...	$v = 51$	51	46	23

In the table which follows, in addition to the absolute velocities of the ions, there is given the force in gravitation units which must act upon one milligramme of the ion to give it a velocity of one millimetre per second. These forces are very large, but Kohlrausch shows that they are of the same order of magnitude as the forces necessary to overcome the friction between such exceedingly small portions of matter as atoms (in which the ratio of surface to mass is very great) and the liquid solvent. The velocities are those which would be produced in a column of liquid one millimetre long, with a difference of potential of one volt at the ends.

Ion.	Vel. mm. per sec.	Kgm.
With Monobasic Acids.		
H, ...	·300	32,500
K, ...	·052	4,800
NH_4, ...	·050	10,800
Na, ...	·034	12,500
Li, ...	·022	61,600
Ag, ...	·043	2,100
Cl, ...	·053	5,200
Br, ...	·057	2,100
I, ...	·057	1,300
Fl, ...	·032	16,000
½ Ba, ...	·031	4,500
½ Sr, ...	·030	7,300
½ Ca, ...	·028	17,700
½ Mg, ...	·025	33,000
½ Zn, ...	·022	13,900
½ Cu, ...	·031	9,800
CN, ...	·054	7,000
NO_3, ...	·049	3,200
ClO_3, ...	·043	2,700
$C_2H_3O_2$, ...	·025	6,700
With Dibasic Acids.		
H_2, ...	·179	54,500
K_2, ...	·043	5,800
$(NH_4)_2$, ...	·039	13,700
Na_2, ...	·024	17,800
Li_2, ...	·012	113,000
Ag_2, ...	·034	2,600
SO_4, ...	·043	4,700
CO_3, ...	·039	8,300
With SO_4.		
Mg, ...	·015	54,000
Zn, ...	·013	23,000
Cu, ...	·013	24,000
SO_4, ...	·024	8,600

When the solution is not dilute, the question of friction becomes a more complicated one, and the ratios of u and v change with the concentration.

m.	u.	v.	
0	·179	·043	for H_2SO_4.
1	·166	·034	
2	·153	·031	
4	·125	·027	
8	·071	·022	

Oliver Lodge has actually observed the velocity of the passage of hydrogen. It moved through a tube filled with sodium chloride dissolved in jelly, decolorizing phenolphthalein as it went. He found the velocity to be ·29 millimetres per second, whereas the calculation of Kohlrausch gave the closely agreeing result ·30.

In November of 1892, J. J. Thomson brought before the Royal Society an account of experiments conducted by Mr. W. C. Dampier Whetham upon the velocity of certain ions. A current was sent through a tube containing $CuCl_2$ and NH_4Cl. The boundary was distinct and its rate of motion could be accurately measured.

	Observed.	*Calculated.*
Vel. of Cu,	·0309	·031
Cl,	·057	·053
Cr_2O_7,	·047	·0473

It is seen by a comparison of observation with calculation that they lead to almost identical conclusions respecting the absolute velocities of the ions. It is therefore safe to assume that the suppositions which underlie the calculated results are in the main correct.

NORTHEAST MANUAL TRAINING
HIGH SCHOOL, PHILADELPHIA.

[*Proceedings of the stated meeting, held Tuesday, April 25, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, April 25, 1893.

Mr. E. G. WILLYOUNG, President in the chair.

The stated meeting of the Section was called to order by the President at 8.10 P.M. There were present fifty-seven members and visitors. The minutes of the previous meeting were read and approved. The treasurer reported a balance of $36.91 in the treasury, and presented bills amounting to $10.32, which were ordered paid.

The meeting was then informally adjourned to allow the members to see the working of the telautograph, the recently perfected invention of Prof. Elisha Gray. The meeting was called to order again at 9.15. A committee, composed of Prof. E. J. Houston and the President, was appointed to endeavor to secure Prof. Elihu Thomson to show before the Electrical Section some results of his most recent work.

The President and Mr. Carl Hering were appointed a committee to provide for lunches at the next two meetings.

Mr. C. Billberg presented two curves taken from one of his sixty-five horse-power motors, illustrating the influence of the iron wire wound over the whole surface of the armature. The one was platted from a test before the iron wire was put on, and the other after, the latter showing a gain of about ten to eleven per cent. in E. M. F., with the armature making in both cases 665 revolutions per second, and having the same field excitation.

Mr. Willyoung showed some interesting experiments with Crookes tubes.

The paper, by Messrs. Willyoung and Northrup, on "Some Methods of Varying the Sensibility of Galvanometers," was referred for publication.

The meeting then adjourned. R. H. LAIRD, *Secretary.*

A LIST OF ELECTRICAL JOURNALS, 1893.

Compiled by Carl Hering.

AMERICAN.

Title.	*Published* *Where.*	*When.*	*Subscription.*
Electrical World, ...	New York.	Weekly.	$3 00
Electrical Engineer, ...	New York.	Weekly.	3 00
Western Electrician, ...	Chicago.	Weekly.	3 00
Electrical Review, ...	New York.	Weekly.	3 00
Electricity, ...	New York, Chicago.	Weekly.	2 50
Electrical Age, ...	New York.	Weekly.	2 00
Mechanic and Electrician, ...	St. Louis.	Weekly.	2 00
The Railroad Telegrapher, ...	Vinton, Ia.	Fortnightly.	1 50
Practical Electricity, ...	Boston.	Fortnightly.	2 00
Trans. Amer. Inst. Electrical Engineers,	New York.	Monthly.	5 00
Electrical Power, ...	New York.	Monthly.	2 00
Popular Electric Monthly, ...	Chicago.	Monthly.	1 00
Electrical Progress and Development, .	Boston.	Monthly.	2 00
World's Fair Electrical Engineering, .	Chicago.	Monthly.	
Electrical Industries, ...	Chicago.	Monthly.	
Mechanical and Electrical Progress, . .	Philadelphia.	Monthly.	
Journal of the Telegraph, ...	New York.		
Electric Spark, ...	Chicago.	Monthly.	1 00
Northwest Electrician and Mining Review, ...	Tacoma.	Monthly.	1 00
Bubier's Popular Electrician, ...	Lynn.	Monthly.	50
Electricity and Railroading, ...	Boston.	Monthly.	1 00
Street Railway and Electrical News, . .	Minneapolis.	Monthly.	2 00

FOREIGN.

In the English Language.

			(In the U. S.)
Electrician, ...	London.	Weekly.	19*s.* 6*d.*
Electrical Engineer, ...	London.	Weekly.	13*s.* 0*d.*
Electrical Review, ...	London.	Weekly.	£1 1*s.* 8*d.*
Electricity and Electrical Engineering,	London.	Weekly.	
Lightning, ...	London.	Weekly.	
Canadian Electrical News, ...	Toronto, Montreal.	Monthly.	$1 00
Journal of Institution of Electrical Engineers, ...	London.	Monthly.	
Electrical Plant (Electrical Industry), .	London.	Monthly.	6*s.*

In the French Language.

Title.	*Published Where.*	*When.*	*Subscription.*
La Lumière Électrique,	Paris.	Weekly.	60 francs.
L'Électricien,	Paris.	Weekly.	25 francs.
Électricité,	Paris.	Weekly.	15 francs.
Bulletin de l'Électricité,	Paris.	Weekly.	15 francs.
Journal du Gaz et de l'Électricité,	Paris.		
L'Industrie Électrique,	Paris.	Fortnightly.	26 francs.
Bulletin de la Société Internationale des Électriciens,	Paris.	Fortnightly.	27 francs.
L'Électricité pour Tous,	Paris.	Fortnightly.	6 francs.
Journal Télégraphique,	Berne.	Monthly.	
Bulletin de la Société Belge d'Électriciens,	Belgium.	Every 2 months.	
Bulletin de l'Association des Ingenieurs Électriciens Sortis de l'Institute Électro-Technique Montefiore,	Belgium.	Quarterly.	

In the German Language.

Elektrotechnischer Anzeiger,	Berlin.	Bi-weekly.	10 mark.
Elektrotechnische Zeitschrift,	Berlin.	Weekly.	25 mark.
Elektrotechnische Rundschau,	Frankfurt.	Fortnightly.	10 mark.
Elektrotechnisches Echo,	Magdeburg.	Weekly.	
Zeitschrift für Elektrotechnik,	Vienna.	Fortnightly.	

[*Proceedings of the stated meeting, held Tuesday, May 30, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 30, 1893.

ELMER G. WILLYOUNG, President, in the chair.

The Section's meeting of this date was called to order by President Willyoung, with an attendance of twenty members and visitors. The Treasurer reported a balance on hand of $17.09.

Mr. Willyoung reported that Prof. Elihu Thomson had written in response to the Section's invitation, that he was unable to appear at this time on account of prior engagements.

Mr. W. N. Jennings exhibited, by a projecting lantern, some lightning photographs. He first mentioned having shown before the Section, at its stated meeting of September 27, 1892, a number of these photographs, taken by him from a moving train, while crossing the prairies of North Dakota, being apparently single flashes, but giving multiple images of telegraph poles and buildings. He stated that, at that time, from actual observation, he had

come to the conclusion that lightning was a rapid oscillation or pulsation along a given path, and if the camera is moved during such a discharge, the resulting photograph would show a series of parallel lines, more or less numerous according to the rapidity of the camera movement. He now exhibited a photograph of a multiple flash of lightning taken from a moving train, the original flash appearing to the eye a single line of light, but in the photograph having even distinct lines, all having the same contour. He also showed a large "ribbon" flash of lightning, which effect, according to Tesla, Thomson, Young and others, was due to camera movement during the discharge. Mr. Jennings pointed out the fact that in the photograph, the telegraph poles, railroad ties and branches from the main stem of the discharge were all sharply defined, which led him to doubt the suggestion that the ribbon effect in this particular case was due to camera movement.

Mr. Thos. Spencer read a paper on "Some Interesting Peculiarities of Alternating Arc Lamps. It was referred for publication

The meeting then adjourned. ROBT. H. LAIRD, *Secretary.*

[*Proceedings of the stated meeting, held Tuesday, June 27, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 27, 1893.

ELMER G. WILLYOUNG, President, in the chair.

The stated meeting of the Section was called to order by President Willyoung, with an attendance of seventeen members and visitors.

Minutes of the previous meeting were read and approved. The Treasurer reported $36.09 on hand, and presented a bill for $3.20 for printing, which he was authorized to pay.

Mr. Paul A. Winand read a paper on "Rotary Magnetic Fields." It was referred for publication.

The President having been obliged to leave and neither of the Vice-Presidents being present, Mr. L. F. Rondinella was elected Chairman, *pro tem.*

It was moved that a vote of thanks be extended to the Secretary of the Institute for his courtesy in placing before the Section an exhibit of "Carborundum," and the data concerning some of its properties. The meeting then adjourned until September 26th. R. H. LAIRD, *Secretary.*

THE CHLORIDE ELECTRICAL STORAGE BATTERY.

BY HERBERT LLOYD, F.C.S.

[*Read at the meeting of the Electrical Section, Tuesday, Sept. 26, 1893.*]

The electrical accumulator which I will try to describe is known as the chloride cell. It is so called because the plates constituting the element are made up of tablets cast from fused chlorides of lead and zinc, held together by a frame or rim of antimonious lead. When these composite plates are cast, however, they are not capable of use in a storage battery. They do not contain material which is in any sense active material, nor material capable of becoming active in a secondary battery fluid. They are not capable of serving as oxygen plates, as they will not absorb oxygen, nor are they capable of use as hydrogen plates, as not only would their immersion in the dilute sulphuric acid of the storage battery result in contaminating the fluid with chloride of zinc, which would be fatal to its proper action as a storage battery fluid, but the effect of the hydrogen liberated would be to form hydrochloric acid, with the chlorine of the chloride of lead, which hydrochloric acid would further contaminate the fluid and make it inoperative as a storage battery fluid. Moreover, these tablets are non-conductors of electricity. It is plain, therefore, that a plate consisting of tablets of chloride of lead and chloride of zinc is worthless as a storage battery plate, and cannot be used as such. Its chemical composition must first be radically changed to fit it for use either as an oxygen plate or a hydrogen plate.

This chemical change is brought about by means of a bath of chloride of zinc or some equivalent substance, in which the plate of tablets is to be immersed in connection with a slab of metallic zinc. This arrangement is, in fact, a primary battery, in which the zinc acts as the positive element, while the tablets constitute the negative element.

This operation may be performed with current produced

by a dynamo, but it is a very tedious and expensive process as compared with reduction by means of zinc.

The electro-chemical action in this combination results in withdrawing the chloride of zinc from the tablets by simple solution in the bath, and the withdrawal of the chlorine of the chloride of lead from the tablets and fixing it in combination with the zinc with the formation of chloride of zinc. It may, therefore, be said that the chloride of lead tablets constitute material which is destined to become active by electrical disintegration, which is brought about when they are connected with the zinc plates in the bath of chloride of zinc.

When this process of electrical disintegration is complete, and the chloride of zinc is washed out of the plate, a mass of crystallized metallic lead is left, which is suitable for immediate use in a storage battery, without the tedious forming process of Planté and without the application of any active material or material about to become active by the processes of Brush and Faure.

To describe in detail the process used in the manufacture of this plate, as it is carried on commercially, I will begin with metallic lead. The first step in the production of chloride of lead is to bring the lead into such a state of subdivision as to make it readily soluble in nitric acid. The old way of doing this was to pour molten lead into water and so granulate it, but a process which is more satisfactory is to melt the pigs of lead in a suitable furnace, and when the lead is brought to a high state of fusion to convey it through a pipe into closed chamber where it is delivered in a fine stream into a jet of dry steam, the result being that the lead is blown into a moderately fine powder and falls on the floor of the chamber. [Sample shown.]

This powder is then shovelled into earthenware baskets suspended in large tanks of dilute nitric acid. When the lead has gone into solution in the form of nitrate of lead, the clear nitrate of lead solution is run off into precipitating tanks, where, on the addition of hydrochloric acid the chloride of lead is thrown down in a fine white powder, nitric acid being set free. This nitric acid is returned to the dis-

solving pots to be used there again in bringing fresh lead into solution. The precipitated chloride is then washed by decantation and thoroughly dried.

The next step is to mix the chloride of lead so produced with the proper proportion of chloride of zinc, when both are melted together. I will show later on the direct effect produced by the chloride of zinc in the plate.

The fused chlorides are next cast into tablets [samples shown] of any desired size or shape, and with a beveled or V-shaped edge as shown. These tablets are then placed in a second mould, called a framing mould, where they are placed at a fixed distance apart to allow the frame of antimonious lead to be cast around them. In this operation, the result most desirable to obtain is to produce this framing lead in as dense a form as possible, so that unlike the material destined to become active it will not be attacked by the oxidizing current when set up in a cell. The ordinary method of casting storage battery grids is, of course, to pour the molten lead into the mould from an ordinary ladle. We have improved upon this method by forcing the molten alloy around the tablets under heavy pressure, with the result of not only forming a dense metallic frame, but also of making a very perfect contact between the pastille and the frame. The pastille, at the same time, on account of its peculiar form is dove-tailed, as it were, into the frame. This form obviates the trouble so noticeable with the ordinary red lead plate, in which the grid is dove-tailed into the plug; that is, the surface of the plug on each side of the plate is of a larger area than the centre of the plug, so that the tendency is for the plug to split in the centre and fall out on either side.

When the completed plate is taken from the framing mould it is placed in the reducing tank in connection with a plate of zinc, as described in the first instance. This reduction process extends over a period varying from twelve to twenty-four hours, according to circumstances.

When reduction is complete, the plate is thoroughly washed in running water. In order to be sure that the very least trace of chlorine has been removed from the plate, all

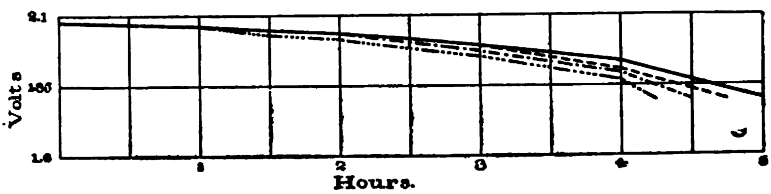
plates are set up as cathodes in a bath of dilute sulphuric acid, plain lead plates being used as permanent anodes in this tank, and a heavy current is passed through the plates for several hours. If the reduction has been incomplete the chlorine will make itself felt in this operation. Excepting through carelessness on the part of the workmen it is practically impossible for the plate to contain any chlorine at this stage.

When the plates are removed from the hydrogen bath they are next set up in forming tanks in connection with the plain lead permanent negatives, and here they are charged continuously for several weeks, or until the crystalline, spongy lead has been completely converted into peroxide of lead. The theoretical amount of current necessary to form a pound of peroxide of lead is about 200 ampère hours, and owing to the beautifully porous structure of the plate this figure holds out very well in practice; the plates will always be found thoroughly peroxidized after they have received a little over the theoretical quantity of current necessary.

The positive plates after formation are then set up with the requisite number of negative plates (the active material of which is in a soft, spongy state as it came from the reducing tank), the lugs or terminals of the plates of each series being burned together with a hydrogen flame, after being insulated in the manner shown in the sample. The cells are then charged and discharged a few times until they give their proper capacity, when they are ready for shipment.

Chloride of zinc is used in this plate for two reasons. In the first place, it is impossible to cast plates of chloride of lead without it, as the casting, on cooling falls to pieces, so the admixture of chloride of zinc is absolutely necessary on that account. In the next place, it will be readily seen that by the use of chloride of zinc it is possible to so control the density of the plate as to produce any porosity that may be desired, and as within certain limits the capacity of a plate is proportional to the porosity, this use of chloride of zinc is of vast importance. The accom-

panying curves show how the capacity of four cells of equal size and weight vary, owing to the different percentage of chloride of zinc which the plates contained when they were cast.



In the manufacture of the ordinary red lead or pasted plate, the density of the material depends mainly upon the energy which the boy uses in pushing the red lead into the grid, and consequently the plates are seldom or ever uniform. In the chloride cell, providing the materials are properly weighed and the mixture thoroughly stirred after fusion, the plates are essentially uniform, as the mixed chlorides become perfectly fluid and every plate cast is exactly like every other plate. It is never necessary to reject any plate for want of capacity.

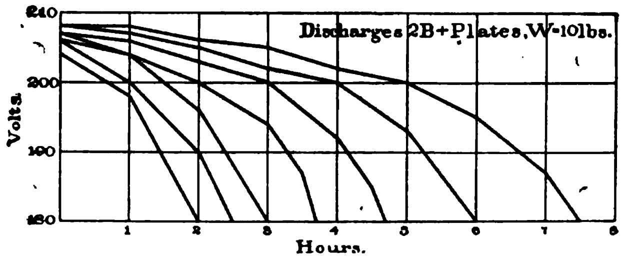
The mixed chlorides on cooling crystallize into a hard, stony substance of a peculiar crystalline nature. After reduction the metallic lead is left in the form of fine acicular crystals, running through the plate perpendicular to its surface, and the elimination of the chlorine and the chloride of zinc provides minute cell spaces around these crystals, so that an immense surface is offered for the absorption of oxygen in the forming process.

Having arrived at the proper amount of chloride of zinc to use, there is no danger of buckling or warping of the plates from undue expansion, as this expansion can be accurately provided for in the tablets.

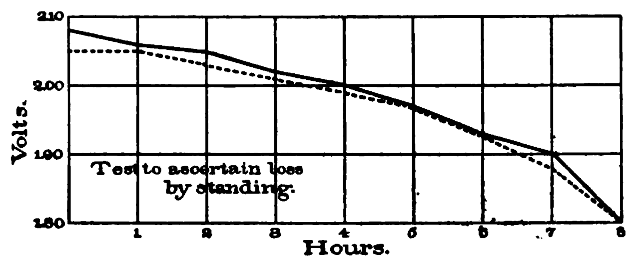
The capacity of cells of this type is from five to six ampère hours per pound of plate. The capacity for weight could be materially increased, but at the loss of durability.

At a discharge rate equal to one-half an ampère for each pound of plate, which is a higher rate than is recommended for any other lead element, this capacity of between five

and six ampère hours per pound can be obtained. At this rate of discharge the efficiency of the cell will be very high, the loss in current being less than ten per cent. and the watt-hour efficiency from seventy five to eighty-five per cent.



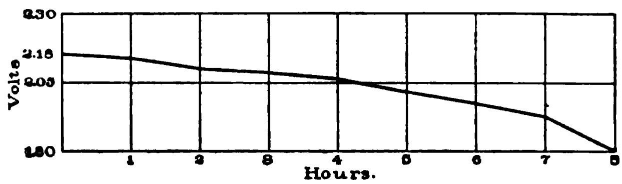
The accompanying set of curves will show the decrease in capacity as the rate is increased. The discharge rate in each of these discharges is above the normal, the lowest discharge being at the rate of three-fourths ampère per pound of plate, and the highest being at the rate of two ampères per pound of plate, or 100 ampères for an ordinary fifty-pound cell, increasing the rate 250 per cent., decreased capacity but thirty-three per cent.



Another set of curves which may be of interest is one showing the effect of allowing a cell to stand charged, the upper curve showing discharge taken immediately after charge, the lower one after the same cell had been allowed to stand charged twenty-four hours. The yield in ampère hours was the same in both cases, but there was a loss in watt hours on standing.

The next curve shows the discharge of a cell at a rate of two-thirds ampère per pound, when it will be seen that

over two-thirds of the capacity was obtained above two volts. At the rate of one-half ampère per pound, over three-fourths of the capacity can be obtained above two volts. This is, in my opinion, a very desirable feature.



While on the subject of capacity, I might mention that a battery of chloride accumulators of about 2,000 ampère hours capacity was installed in the building of the Provident Life and Trust Company, Fourth and Chestnut Streets, in December, 1892. The following letter from the architects, who had the awarding of the contract, speaks for itself:

In regard to the storage battery which you have installed in the Provident building, we would say in the test the battery delivered 1,894 ampère hours, and when the discharge was stopped, as there was still a surplus of five volts, it was evident that the battery was far from being exhausted.

Considering that your guarantee was exceeded by over forty-eight per cent., it certainly speaks very highly for the battery, and is very satisfactory.

Very truly yours,

[SIGNED] FURNESS, EVANS & CO.,
Architects.

The following diagrams, obtained from discharge of the chloride cell on a street car on Lehigh Avenue, in this city, will show the variable loads to which storage batteries are subjected in traction work. In the first, the discharge current ran as high as 200 ampères for a cell weighing less than forty pounds; in the second, over the same road, the current did not pass 100 ampères. One hundred and four cells in series.

The next diagram shows a discharge obtained from a battery of ninety-six cells of the type here shown, on the road of the Metropolitan Company, Washington, D. C. The load in this case was perhaps less than average, the tracks at the same time being in fairly good condition. The trip was about twelve miles, and several five and one-half per cent. grades were encountered, and over fifty curves.

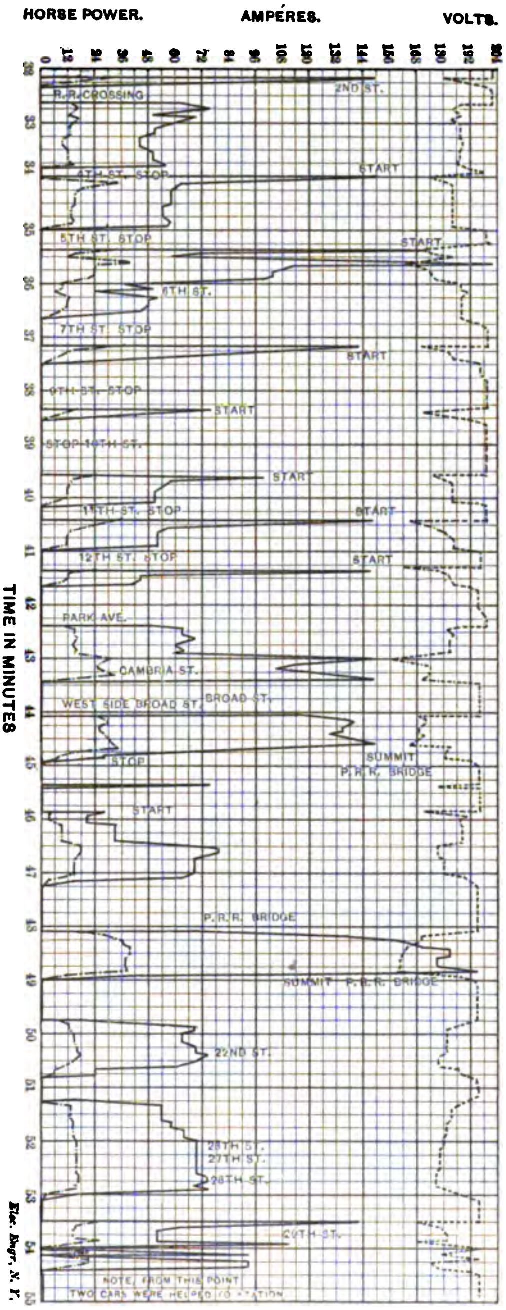


Diagram showing variations in load—Lehigh Avenue Railway, Philadelphia.

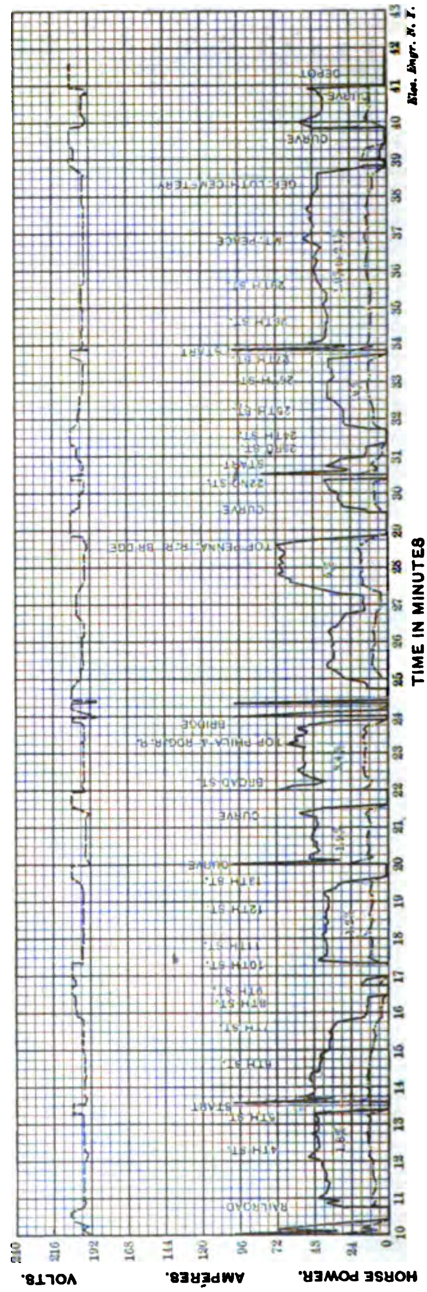


Diagram showing variations in load—Lehigh Avenue Railway, Philadelphia.

A more recent curve, taken after the cells had been in use five months, shows an improvement over this one in voltage.

An examination of the complete element will show the special care that has been given to the insulation of the plates. It is well known that the liability of a storage battery to short-circuit has been one of the main causes of trouble. To overcome this, we envelop the positive plate in a piece of beautifully woven asbestos cloth. Between this positive so protected and the negative plate we place a perforated, grooved board of insulating material, the perforations in this board being made opposite the pieces of active material in both plates, leaving free circulation of the electrolyte between the plates, at the same time keeping the asbestos cloth pressed against the face of the positive plate, causing it to form a tight covering over the face of the active material, and while making the plate absolutely safe from short-circuit, it also adds very wonderfully to the life of the cell, since the peroxide is held in position where it can perform useful work instead of being deposited on the bottom of the cell. The channels in the board provide for the free circulation of the electrolyte, and also allow for the escape of the gases. In traction work this form of insulation is found very beneficial, as the cell is vastly more durable than anything that has been before produced and at the same time there is no unnecessary liquid to be spilled over the car.

It may be of interest to state that the company manufacturing this type of cell in France has supplied batteries for nearly two years to the North Paris Tramway Company, who operate two or three roads with battery cars, about forty cars in all, I believe. I was on these cars about a year ago, and they certainly were doing good work. The cars are about twenty-two feet long, and have seats on the roof, having seating room for fifty-four passengers.

The Paris factory has for some years turned out over five tons of plates a day. They equipped the Popp stations in Paris with these accumulators some three years ago, which have been in constant use ever since. There are twenty-four sub-stations all charged in series, the lighting

being done entirely from the batteries, there being two sets in each station, one being discharged, while the other one is charged. There are in the neighborhood of 100,000 lamps run daily from these cells, the result obtained being very satisfactory, since, in addition to the benefit derived from the batteries as a store, they also act as transformers, as the batteries are charged in a 3,000-volt circuit, each station turning out current to its immediate vicinity at 110 volts. The plates in some of these cells weigh 100 pounds each, the complete cell weighing over a ton, and discharging at a rate of from 1,000 to 2,000 ampères each.

A company has recently been formed in England, for manufacturing these cells, which has just completed works near Manchester, capable of a very large output. That company is controlled by Messrs. Mather & Platt, probably the largest electrical engineers in Great Britain, and the business is to be managed by Dr. Hopkinson. Under such management there can be very little doubt about the success of the business.

The demand for storage battery in Europe is very great. European manufacturing companies, therefore, are not compelled to educate the public into their use.

DISCUSSION.

MR. HERING.—How long have you used the asbestos wrapping?

MR. LLOYD.—About two years.

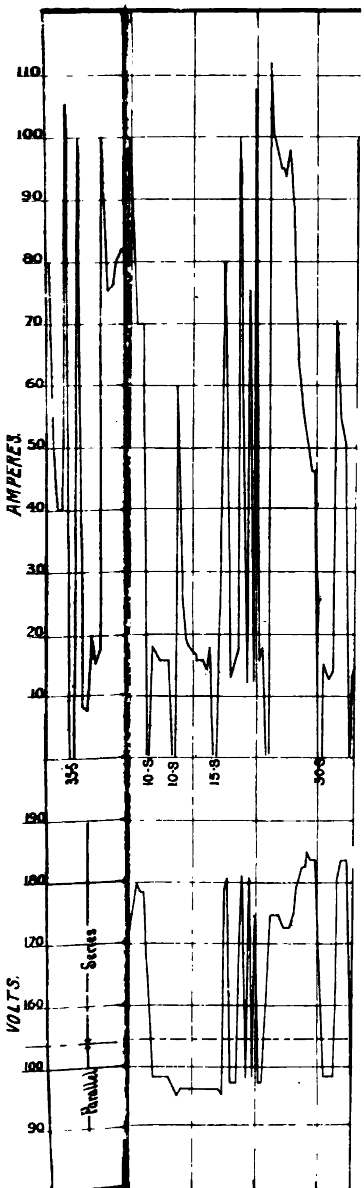
MR. HERING.—It has been the experience of many that the asbestos by and by becomes quite mushy and loses its consistency.

MR. LLOYD.—That must have been due to the character of the asbestos used; we have had no such trouble in our cell.

MR. SPENCER.—What is the advantage you claim for your battery over other former batteries?

MR. LLOYD.—Two of the greatest advantages. The first is greater capacity for weight, and the second greater durability. The battery has been on test alongside of eight

Jour.



ON CAR OF

other systems in Washington, D. C., for the past six months and both of these claims have been proved to be correct.

MR. SPENCER.—Is it superior to the so-called alkali battery?

MR. LLOYD.—I cannot say much about that cell, as it is impossible to obtain one. However, from what I know of the type of battery, which is not at all new, it is of very little value for real work. Its extremely low voltage and its liability to reversal on account of the great difficulty in depositing the zinc on a negative plate are very great disadvantages.

MR. HERING.—The active material of the positive plate expands and contracts. Now, if it is confined as in this cell, something must give way when it expands and something must take the place of that volume when it contracts again. Now, I have noticed in plates in which there were large pieces of active material, as in this one, that the expansion of the active material pushes the lead aside, the lead being soft and yielding, then, when the material contracts again the joint between the active material and the lead is broken. Such a loose joint in an accumulator, that is, a loose joint between the active material and the lead, will always cause sulphating at that joint, so that when the plate is broken, some of this white sulphate will be found between the lead frame and the active material. I noticed in the earlier forms of this battery, which I examined some four years ago, that there was always a white layer between the active material and the lead, and I was curious to know whether you have overcome the difficulty.

MR. LLOYD.—We overcome this trouble entirely by making the pastille sufficiently porous to allow for this expansion and contraction in the active material itself.

MR. HERING.—How long have any of your plates been in use continuously?

MR. LLOYD.—We have some that have been in constant use for two years, and they are in use to-day. The time a battery is in use is not important; the amount of work done is the all-important item. A company in France, which has been manufacturing these plates for several

years, maintains the battery perpetually for ten per cent. per annum of the first cost.

MR. HERING.—I have also noticed in cells of this kind that if they are discharged very rapidly the material discharges completely right next to the lead conductor, so completely that it becomes almost an insulator, and you can get nothing more out of the battery, not even with a short circuit, until you have charged it again, but you need charge it only for a very short time, a minute or so, in order to charge the material close to the lead. Have you noticed this?

MR. LLOYD.—This may have been so in plates with very large tablets (say four inches), but in this plate, in which no part of the active material is three-eighths of an inch from the conductor, it is certainly not the case. The very low internal resistance of the cell tends to prove this. At Mr. Willyoung's request, I will describe the apparatus we use for pumping the molten lead into the mould.

We place in the centre of the pot of molten alloy, a cylinder, which is connected to a tank for obtaining air under heavy pressure, 100 and 200 pounds to the square inch, and in the pipe connecting the tank to the cylinder, we place a three-way air-cock. At the bottom of the cylinder, so as to draw the lead into the cylinder from the bottom of the pot, where there is no liability of dross or such impurity getting in, we place a ball valve.

The cylinder is also provided with an outlet, to which the mould that is to be filled, is connected. When the air-cock is turned so as to confine the air in the tank, the weight of the column of lead in the pot opens the ball valve and fills the cylinder with molten metal up to the level of the metal on the outside. When the cock is turned so as to allow the pressure to be exerted on the surface of the metal in the cylinder, the ball valve is closed and the metal driven out through the outlet which is connected with the mould. When the mould is full the air-cock is again turned to its original position, shutting the air in the reservoir and allowing the compressed air in the cylinder to escape, when the lead again runs up in the cylinder to the level of the lead in

the pot. This operation, of course, can be repeated indefinitely; in fact, we have been able to cast six plates a minute with this apparatus.

MR. WILLYOUNG.—My experience in storage batteries has been confined to the use of them. I have never made much of a study of the different classes of batteries, but I must say my experience in the use of them has been extremely unfortunate. I have tried nearly every make of battery on the market except this one, and have never found one that would stand use over nine months without having the positives replaced. I have done that twice now, and have replaced the batteries simply because we could not get along without them, even at three times their cost. I simply had to have them, and I finally came to the conclusion that, until somebody proves to me there is something different than I have seen, I will buy no more if I can possibly avoid it. They are certainly valuable if you can get one that is durable, and if this battery has durability, a great many people will rejoice. I am not prepared to say whether they are any better or worse than the many other cells that have been put on the American market.

The Section is very grateful, indeed, for the paper Mr. Lloyd has delivered. I am sorry he did not go a little further into some of the details of the processes he employed, some of which are exceedingly interesting and ingenious.

[*Proceedings of the stated meeting held Wednesday, September 27, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 27, 1893

The stated meeting of the Electrical Section was called to order at 8.10 P.M by President Willyoung, with twenty-one members and visitors present.

The minutes of the meeting of June 27th were read and approved.

The Treasurer reported a balance of $35 89 on hand, and presented bills for printing $3, and postage and mailing of notices $8.75, which were ordered paid.

A paper on "The Chloride Electrical Storage Battery," by Mr. Herbert Lloyd, was read by the author and discussed by Messrs. Hering, Spencer and Willyoung.

The meeting then adjourned. R. H. LAIRD, *Secretary.*

SOME INTERESTING PECULIARITIES OF THE ALTERNATING ARC LAMP.

BY THOMAS SPENCER.

[*Read at the meeting of the Electrical Section, held June 27, 1893.*]

Although arc lighting by means of direct currents has been practised in this country for nearly fifteen years, it is only quite recently that an attempt has been made here to utilize the alternating current for that purpose, although it is a historical fact that the very first attempts made to introduce arc lighting for street illumination was by means of such a current. I refer to the Joblochkoff candle. Joblochkoff found that he had to use an alternating current to make his two carbon pencils, which composed his candle, burn away equally. Since Joblochkoff's time there has been a great deal of work done in Europe, and especially in Germany, where greater progress has been made in the electrical sciences than any other part of the eastern continent, towards utilizing the alternating current for arc lighting, and I have the pleasure of showing you one of the latest productions of that country (both as to lamp and carbon to be used with it) this evening. The lamp itself, though, being an American production, it being manufactured by the Helios Electrical Company, of Philadelphia, under patents of the German company of the same name. This lamp I will speak of later.

As I said before, it is only quite recently that alternating currents have been utilized for arc lighting. The first systematical attempt of the sort was, no doubt, that of the pioneers of alternating currents in this country, the Westinghouse Electrical Company, of Pittsburgh, Pa., when they put upon the market their well-known alternating series system. This was, no doubt, brought about by a circumstance, and that circumstance was the invention by Mr. William Stanley, who was then consulting electrician for

that company, of a wonderful constant current alternating current dynamo. This machine I look upon as one of the most beautiful in its performance of anything in the whole range of electro-dynamic machinery. It was my pleasure to be so situated as to have the handling of two of the first machines of this kind sent out by the company, the performance of these machines were simply wonderful. I have time and time again switched one of these machines from full load; that is, sixty arc lamps, each taking forty-five volts, to a dead short circuit, with only a variation of a half ampère in the current, and this without any mechanical regulation. I would say, in passing, that with this machine the only thing to be feared was an open circuit, and that the safe way to run the machine was dead short circuited.

The principle on which this machine worked was very vaguely understood for some time, the inventor himself having a very complicated explanation, based on armature reaction, but no doubt the correct explanation is this: The machine has an armature of the tooth form, on which there is wound quite a large amount of wire, and as a result the electro-motive force generated by the machine is quite large, but on account of the way the armature is constructed there is a large self-induction. These two factors being so great the actual resistance in the current becomes insensible in comparison with them, so the current is practically independent of the resistance in circuit; or, in other words, constant.

This can more clearly be seen from the following equation:

Where

c, is the current.

E, the electro-motive force.

R, the total resistance in the circuit, including the resistance of the arcs of the arc lamps.

L, the coëfficient of self-induction.

$p = 2\pi n$, where n is the frequency.

$$c = \frac{E}{\sqrt{R^2 + L^2 p^2}}$$

Now, if E and L are very large in comparison to $L R$, we have

$$c = \frac{E}{L p}$$

or the current is constant, no matter what the external resistance may be, providing it is not too large.

With such a machine the Westinghouse Company thought they had solved the problem of arc lighting by means of alternating currents, but in this they were mistaken; in fact, this was really the easiest end of the problem, and although this machine has now been known for over three years, this system has made little progress, due to

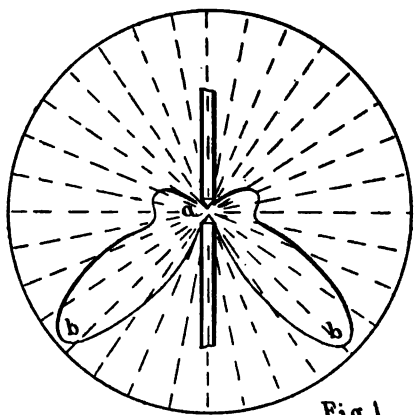


Fig. 1.

the fact that these lamps did not come up to the standard set by the direct system in common use.

The fact is, that here in this country an alternating current arc lamp has been studied entirely in those lines on which a direct current lamp was found to give the best results, while European practice shows plainly that a treatment entirely different should be followed.

Let us study the arcs formed by the two kinds of currents; first, as regards the distribution of their illuminating power.

Let *Fig. 1* represent the two carbon pencils in a direct arc lamp, where the upper pencil is supposed to be positive. Suppose we take a, the arc, as a centre of a circle,

and suppose we plot off on each radii the candle-power in the direction represented by it. Now, if we trace a curve through all the points thus found, we have a curve, as shown in *Fig. 1*, from which we see that nearly all the light is thrown down in the direction *a b*. This is due to the fact that nearly all the light from an arc lamp comes from the crater on the positive carbon.

Fig. 2 shows the curve for an alternating arc, which you see is altogether different from the first curve, there being four wings instead of two, as in the first curve, and these wings are shorter.

This distribution of light, of the alternating arc, has

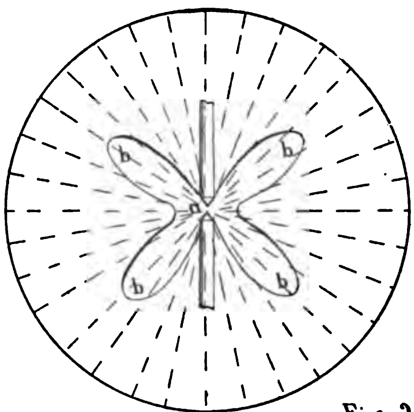


Fig. 2.

always been looked upon as a failing, for the light represented by the two upper wings is usually thrown up and wasted, especially if the lamp is out of doors. This defect has been in a great measure remedied in the lamp before you, by making the lamp focusing; that is, making the arc remain always in the same place, and using a white reflecting plate close above the arc. This plate will reflect something like eighty per cent. of the light incidenced upon it. There is another point in which there is a great difference in the two currents, it is this: One of the first things noticed about the alternating current, was that there was very little arcing at switches where currents of large ampèrage were broken. This pecu-

liarity was looked upon as a particularly valuable feature for, in the construction switches, the arcing was the principal thing to be guarded against, especially where high voltages were to be broken. I think, with the general introduction of alternating current plants, this property is not appreciated. One has only to stand and watch the arc that follows a plug switch in a direct arc switch-board, where the voltage is not over 2,500 volts and ten ampères, and to imagine what the result would be if the alternating current should suddenly acquire the same property, on some of the beautiful switch-boards for incandescent lighting of about the same voltage and much larger ampèrage, when the switches began to be thrown. There has been a great many theories about this property of the alternating current, but it is about settled that it is due to the fact that at a certain instant there is no current flowing to keep up the temperature of the vapor through which the current is flowing, sufficient to maintain a strong, hardy arc, and as a result it is easily broken. Now, this property, although it is just the thing we want, as far as switches are concerned, is far from desirable when we come to use the alternating current for arc lighting. It is evident from what has been said that an alternating arc is much less hardy than that of a direct current, of the same current density. We see, therefore, that it is a mistake to follow the lines of the direct system in devising an alternating system. What is desired is to get as much heat generated as possible in the flame, so as to keep up the temperature of the vapor through the time when the generation of heat practically stops for the instant. This is best illustrated by *Fig. 3*, where *a a a* is the current curve and *f f f* the temperature curve of the flame for the same instants, and *c c c* the minimum temperatures, which the flame reaches. Now *c c c* will be larger the larger the current, and the arc will be more hardy.

So it would seem that the only way to produce a good alternating arc lamp, is to use a large current, but a large current means a large candle-power, unless we lower what is called the counter electro-motive force of the arc, or the

drop in electro-motive force which occurs at the crater itself. If we refer to *Fig. 4*, where *A* and *B* are the carbon points, the distance between them being exaggerated for convenience, and suppose the drop in potential plotted from one point to the other, assuming *A* the positive carbon, we find for the direct system, at the point *a*; that is, at the crater, that there is a sudden drop of the potential to a point marked *b*. This drop is what is known as the counter electro-motive force of the arc. For the remaining part of the distance the drop is more gradual, and varies as the current. This is the part due to the drop in the flame itself. So it is apparent that if we could reduce the counter electro-motive force, leaving as large a loss of energy in the flame as possible, we would get an arc which would be much less affected

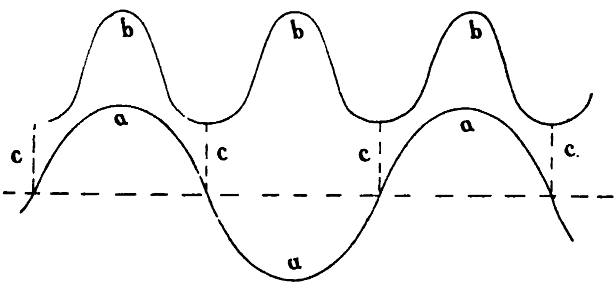


Fig. 3.

than with a smaller current, at the same time without any larger output in watts for the lamp. This has been done in the lamp before you by the use of a special low voltage carbon, which allows this lamp to give an illuminating effect with twenty-eight volts and ten ampères, equal about that given by a forty-five volt seven ampère direct-current lamp. Referring again to the counter electro-motive force, I would say that there has been a great deal of controversy over whether such a thing really existed. I myself am one of the party who believe in its existence. In fact, there is a strong current setting in the direction of that belief. I myself have been convinced that there was a real electro-motive force in the arc by studying the alternating arc itself; in fact, there are reactions in the arc which could only be

explained by the existence of a counter electro-motive force. A gentleman in England, whose name I have forgotten, has recently tried an experiment of heating a carbon juncture in a hydroxygen flame, and was able by this carbon thermopile to get quite a difference of potential between the two carbons. He claims that his results were such as to account for the counter electro-motive force of the carbons had been raised to the temperature of the arc. Also quite recently Sylvanus Thompson has tried quite a number of experiments bearing on this subject, and has come to the conclusion that the electro-motive force is the result of the energy which disappears as latent heat in the volatilization of the carbon in the crater.

There is another peculiarity of the alternating arc which is the most serious objection to it, from a commercial stand-

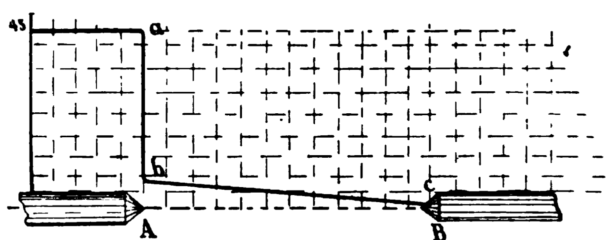


Fig. 4.

point, and that is the noise made by the arc. Even this has been attacked, and so overcome that it is no longer the objection it was in the early forms of lamps using alternating currents. The cause of this noise is due to the constant variation of temperature of the flame, as I have described already, which produces an expansion and contraction in the surrounding air. The result is a musical note depending on the frequency of the current. That there is a real rise and fall, even in the light given out by the arc, can be shown by moving a white stick, or better a short piece of white wire moved back and forth rapidly near the lamp, when the white band, caused by the persistence of impression in the eye, will be observed to be broken up into bands, showing that the light is varying with the alternations.

The noise is, I find, a function of the form of the current curve. This came under my notice in trying to substitute a choking coil in place of a resistance to absorb the excess electro-motive force above what was wanted at the arc. I noticed that the noise was considerably increased by the coil over the resistance. You can see that this is the case by the experiment I have arranged before you, which is so wired that either the resistance or coil can be used. You will observe that when the lamp is burning on the coil, there is considerable more noise than when the resistance is in circuit. The reason why this is the case will be explained by referring to *Fig. 5*, where let *a a a* be a simple curve of sines, which is very near the case, with a well-designed alternating dynamo. Let this curve be deformed

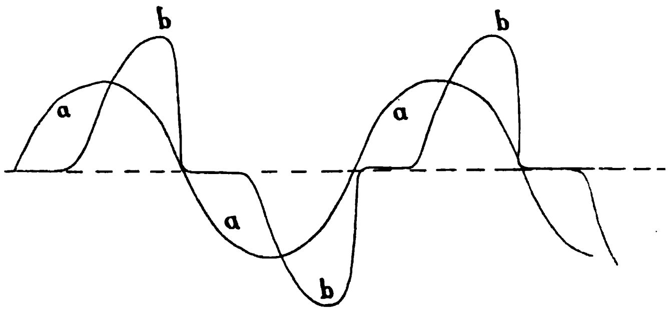


Fig. 5.

by the current represented by it, passing through a choking coil with iron. The deformed curve will be something like the curve *b b b*, due to the lack of constancy of the permeability, and to hysteresis in the iron. If we look at this curve we will notice an abrupt rise in it, which means a sudden rise of temperature in the flame; or, in other words, we would have a sort of explosion, and as a result this form of current curve would be more noisy. There is no doubt but the form of the current curve, which would be the best as far as sound is concerned, is that of the simple sine curve, for in this curve the current rises gradually, and sinks away gradually.

One thing which puzzled me for some time was that I found that a choking coil, which contained no iron, even

made more noise than when a resistance was used. As there was no changing permeability or hysteresis, in the arc, the cause for this increased noise was not quite so apparent. The explanation, no doubt, lies in the fact that no machine gives a true sine curve, but in most cases the curve is symmetrical as regards the rise, and fall, as will be seen by the curve *a a a*, *Fig. 6*, which is supposed to be the form of curve given by the dynamo. Now, a choking coil without iron would deform this curve to the form shown in the curve *b b b*, on account of the change of phases which it would bring about in the different harmonies which make up the compound wave coming from the dynamo.

It is found that when the frequency is reduced the noise is greatly decreased; for instance, lamps burned by means

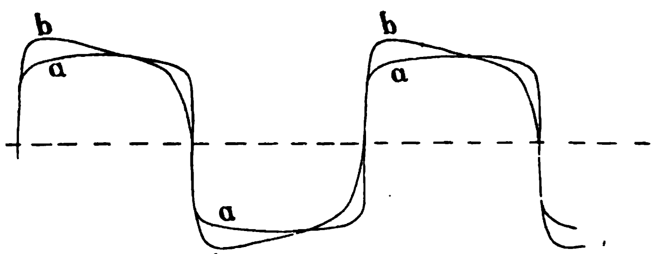


Fig. 6.

of the current supplied by some dynamos recently turned out by the Westinghouse Electric Company, which have a frequency of 7,200, practically made no noise. On the other hand, Mr. Tesla, by going the other way; that is, by raising the frequency above the audible point, made a perfectly quiet arc, but as high frequency introduced so many other objectionable features, I hardly expect to see this method very extensively introduced.

There is what you might call, still, a mechanical way by means of which the noise can, in a measure, be reduced, and that is by running with a short arc. The reason for this is self-evident, for by so doing you keep the flame well inside the hot walls of the carbon, which do not fluctuate as much in temperature as does the flame; as a consequence

the surrounding air is not so much affected, and the result less noise.

I will say in closing that an alternating arc lamp is something very much to be desired, as it forms one of the links in a chain towards which all electrical engineering is now drifting. I refer to the designing of a central station so that all kinds of electrical work can be done by one kind of current, which can be supplied by one kind of machinery at the central station. Not as now by several different kinds, as I saw to-day, a station using at least five different kinds of dynamos. That the alternating current is to be the current settled upon no one will deny, on account of its great flexibility. Therefore, I believe the alternating arc lamp has a great future before it, even greater than the series arc has had in the past. It, therefore, gives me pleasure to exhibit to you to-night a lamp, which I believe, embodies in its construction the most advanced idea in alternating arc light engineering.

[*Proceedings of the stated meeting, held Tuesday, September 27, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 27, 1893.

ELMER G. WILLYOUNG, President, in the chair.

The stated meeting of the Electrical Section was called to order at 8·10 P. M., by President Willyoung, with twenty-one members and visitors present.

The minutes of the meeting of June 27th were read and approved.

The Treasurer reported a balance of $35.89 on hand, and presented bills for printing, $3, and postage and mailing of notices, $8.75, which were ordered paid.

A paper on "The Chloride Electrical Storage Battery," by Mr. Herbert Lloyd, was read by the author and discussed by Messrs. Hering, Spencer and Willyoung.

The meeting then adjourned. R. H. LAIRD, *Secretary.*

[*Proceedings of the stated meeting, held Tuesday, October 24, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 24, 1893.

ELMER G. WILLYOUNG, President, in the chair.

The stated meeting of the Section was called to order at 8 P. M., by President Willyoung, twenty-three members present.

In the absence of the Secretary, on motion, Mr D. A. Partridge was appointed Secretary *pro tem.*

The reading of the minutes of the previous meeting was dispensed with.

The names of Mr. Bacon, E. R. Keller and G. C. Common having been proposed for membership, they were duly referred to the Committee on Admissions.

The Chair announced that a series of lectures, to alternate with the business meetings of the Section, had been arranged for, and that Dr. Henry Morton, Mr. J. J. Carty, Prof. Elihu Thompson and one or two others had expressed their willingness to address the Section.

Mr. Carl Hering read a most interesting collection of notes on "Recent Progress in Electricity Abroad," taken mostly from European journals.

Some interesting discussion was elicited upon many of the points touched upon in Mr. Hering's paper.

Mr. L. F. Rondinella exhibited a collection of lantern slides of subjects from the Columbian Exposition, and gave a short talk descriptive of the views.

On motion, adjourned. D. ANSON PARTRIDGE, *Secretary pro tem.*

NOTES ON RECENT DEVELOPMENTS IN ELECTRICITY ABROAD.—PART I.

BY CARL HERING.

[*A paper read at the stated meeting of the Electrical Section of the Franklin Institute, October 24, 1893.*]

Busy men, as most conscientious electricians are, generally have little time to study the vast amount of periodical literature published weekly, even if the journals were all accessible to them, and if the foreign languages in some of them were no hindrance. For the benefit of such busy men the following notes were compiled from articles in the principal foreign electrical journals for the present year: as they are all taken from periodicals, they necessarily contain nothing which has not already been published, and

they are therefore intended to form a mere *résumé* or index to call attention to what has been done, leaving those who are interested in any of the subjects to look up further details for themselves.*

Electro-physics.—Taking up first the subject of electro-physics, I will limit myself to only a few of the more interesting papers, as most of that which has been published in this branch belongs to the subject of physics rather than to electrical engineering.

Mr. Arno has shown that a rotating electric field, quite similar to the well-known rotating magnetic field, can be produced, and that this can be applied to the construction of an electrostatic rotary field motor; it is only of theoretical interest, as the power developed is necessarily exceedingly small. There has been some discussion as to whether there is such a thing as electrostatic hysteresis, on which this phenomenon is supposed to be based, but authorities still differ.

Prof. Elihu Thomson states that he has succeeded in making a transformer in which a continuous current is made to give alternating currents of any desired frequency, and which contains no moving parts. Several other writers have shown how the frequency of an alternating current may be tripled and doubled quite readily in an alternator without increasing the speed. Dr. Sahulka has shown that a condenser may act as a transformer of current into phase, so to speak, that is, that a condenser in parallel converts a weak current of small phase difference into a strong current of large phase difference, and *vice versa.*

Several instruments have been described by means of which the curve of an alternating current can be resolved into its component sine curves.

Dr. Heydweiller has made a long series of tests with striking distances, giving quite a complete table of the results, which might be used to advantage in place of the very old table of De La Rive, which has been the standard

* More complete abstracts of all the articles referred to will be found in the "Digest" of the *Electrical World,* from February 4, 1893, to date.

of reference for so many years. The much-vexed question of the sparking distances has also been discussed by Mr. Peace, in a Royal Society paper, in which he gives what constitutes, probably, one of the most complete and reliable tests made for certain ranges. Mr. Precht has shown that lightning-rod points begin to discharge only when the potential has reached as high as 15,000 volts, and even extremely fine points can be charged to 2,500 volts before they will discharge continuously; also that a bunch of points must be charged to a higher potential than a single point in order to discharge; he believes that in many cases the points of lightning rods are inactive. The difference of potential of the air at the top and at the bottom of the Eiffel Tower was found to vary from 3,000 to 7,000 volts, increasing sometimes to 10,000.

Mr. Arons described an arc lamp in which the arc is produced in vacuum between electrodes of mercury, showing some interesting results; the voltage and the current are quite low, but unfortunately the amount of light generated is not given.

In an interesting experiment made by Dr. Gore, he has shown that mechanical pressure may be converted into an electric current; the pressure is applied to an electrolyte, which then generates a current at the expense of nothing but the pressure.

A number of improvements have been described by Wimshurst and others in so-called electrostatic machines.

Numerous experiments have been described with stretched wires through which a current is passed; under certain conditions the wire will vibrate, some parts becoming luminous, while others remain cold; in another case the wire itself became deformed as if it had been placed between two files.

A number of articles have been published on the electrical transmission of sight, but although interesting, they appear to contain nothing new or of any great importance, and the matter may still be considered as an unsolved problem.

Much has been done in the line of the researches started

by Hertz, but this is beyond the province of the present paper.

Professor Dewar has made some very interesting experiments with liquid oxygen, which he now makes in large quantities. Liquid oxygen is magnetic, and he has shown that in liquefied air the magnet will not suck out the oxygen, even though the nitrogen is not magnetic. But the most interesting parts of his researches, for electricians, are those which show that the resistance of all pure metals is probably zero at the absolute zero of temperature; or, in other words, at that temperature electricity will pass through pure metals without any C^2R loss; alloys, however, do not follow this rule. Professor Dewar has also succeeded in converting air into a solid. It has been stated that the magnetic moment of oxygen is about one-thousandth that of iron, and that liquid oxygen is an excellent insulator.

Much has been written on the electro-magnetic theory of light, but it is beyond the province of this *résumé*. An English scientist stated that electro-magnetic waves are strictly similar in their nature to light waves, differing only in the wave length. The light waves are about one-fifty-thousandth of an inch long, while the electro-magnetic waves that have been investigated are from a few inches to many yards in length.

Messrs. Lagrange and Hoho gave what appears to be the first published description of the phenomenon, now so well known, of heating a metal by its contact resistance with water. The heat produced is exceedingly intense, and is generated very rapidly—two qualities which may make the process one of considerable commercial value.

It is claimed by Mr. Sanford that Ohm's law should be qualified, as he believes that he has found that the nature of the medium surrounding a wire has an appreciable effect on the resistance of the wire; his conclusions, however, do not appear to be generally accepted, and it will be fortunate if it turns out that he is not correct.

Mr. Packey claims to have found by photography that there is what he calls an electrical spectrum different from the remaining part of the spectrum, and that it contained only the "electric rays" of the spectrum.

Several papers have been written, showing how the amount of light can be measured by absolute instead of comparative methods, but none of these appear to have as yet been put into the form of a practical photometer.

A number of interesting phenomena have been described with high tension and high frequency currents, which, however, time does not admit of mentioning here. Much has been written lately endeavoring to explain the phenomenon that an incandescent lamp may be brought to great brilliancy by high tension, high frequency currents of exceedingly small ampèrage; most of the writers claim that it is due to skin-deep conduction, but this has been seriously questioned by several equally high authorities, and it can therefore still be considered as a phenomenon which cannot be explained. Dr. Leduc has shown that high tension alternating currents produced by electrostatic machines have properties which are analogous, but not identical with, those which Tesla uses. Mr. Rimington has shown that many of the phenomena with vacuum tubes can also be produced with such tubes when they contain no electrodes, and when they are placed in electrostatic fields. Lord Armstrong showed an interesting experiment, in which a cotton thread was carried bodily from one glass of water into another by a current from an influence machine.

A new and important re-determination of the mechanical equivalent of heat has been made by Messrs. Griffiths and Clark; they found it to be 778·99 foot-pounds.

Among the interesting articles of a speculative nature is one in which a French writer endeavors to show that the absolute temperature has the same dimensions as electrical potential.

Magnetism.—Mr. Meylan has shown that the great care taken by some makers to have perfect joints in dynamos is not justifiable, as the additional excitation required to overcome the effects of joints in a magnetic circuit is only about one to two per cent.; in transformers, however, the question is quite different, for if joints could be avoided, there would be a gain of ten to fifteen per cent. in the magnetizing current; he believes furthermore that the pre-determination of

the characteristics of transformers having a closed magnetic circuit is very uncertain, and probably of little practical value.

Mr. Abdank Abakanowicz has described an interesting arrangement by means of which the effects of hysteresis may be compensated in measuring instruments by the simple addition of a second electro-magnet, properly designed and proportioned.

In Russia, a local north pole of the earth's magnetism has recently been found, thus showing that there are at least two north poles of the earth.

Units, Measurements and Instruments.—Many new instruments and new methods for making various measurements were described, but they are too numerous to mention here. Those interested in the measurement of self-induction will find several articles on the subject in recent numbers of *La Lumière Électrique*. Professor Fleming, in his recent Cantor lectures, has given a very good summary of the subject of the practical measurement of alternating currents.

The very extended researches which have recently been made with the Clark standard cell seem to show that it may now be considered as a very reliable and accurate standard, provided it is properly made. On the other hand, it appears that the Daniell standard has been abandoned, at least when accuracy and reliability are of great importance. It appears that the Clark cell may now be relied upon within one part in 10,000; that is, within one-hundredth of one per cent.

A number of tests have been made of the Elihu Thomson wattmeter, all of those published giving very favorable results; this, coming from abroad, is significant. Professor Fleming has called attention to the fact that meters placed in cellars are often subjected to great changes of temperature, producing an error of from ten to fifteen per cent. in the readings, a subject which he thinks ought to be considered more than it is in designing meters. Several forms of ohmmeters have been described, chiefly for use in measuring high resistance and insulation. The literature on the copper voltameter has received an important addition by the paper of Dr. Ottel; he shows, among other things, that the addi-

tion of alcohol makes the actual deposit more nearly equal to that required by theory; also, that an acid solution is better than a neutral one.

Much has been written about locating faults in underground mains, but most of the methods are either impracticable or rather cumbersome, requiring the patience of a German to apply them. Apparently successful high resistances have been made, consisting of rods of a mixture of plumbago and clay. An interesting and simple method for measuring the magnetic qualities of iron was described by Dr. Behn-Eschenburg, in which the underlying principle is that the magnetic circuit is suddenly broken, which enables both the permeability and the residual magnetism to be readily determined with very simple apparatus.

Much has been written, especially by the French and Germans, regarding the behavior and the calculation of condensers for commercial use in alternating current circuits; although interesting, the results will be of little use until condensers become cheap enough to be used in practice. A feature of interest, if true, for all condensers, was reported in an English paper; it was shown that a condenser which was excellent at normal temperatures, possessed very bad insulation when the temperature approached the freezing point of water.

Recent experiments with the arc have apparently shown that its temperature is constant, being about 3,500° C., and that the amount of light emitted per unit area of crater surface is also constant, for which reason some have urged its adoption as the unit of light; the amount of light given off per square millimetre of crater surface is given as about seventy candles. A French scientist suggests a photometric standard made of phosphorescent zinc sulphide, which, in common language, might be called luminous paint. If exposed to the light it will afterward emit light, the intensity of which seems to be independent of the original source of illumination, of its duration, and of the thickness of the layer. Among the different forms of photometers the Lummer-Brodhun type seems to be meeting with increasing favor. Several curious forms of photometers have been

described, in one of which light is absorbed and measured by a semi-translucent screen of increasing thickness, and, in another, letters printed on successive sheets, each one with a darker background than the preceding, are used, but both are, of course, only very crude instruments.

For measuring extremely high temperatures, as in furnaces, and also for extremely low temperatures approaching the absolute zero, physicists seem to have found electrical methods the most reliable. For high temperature thermometers, Dr. Barus concludes from a long series of experiments that a couple made of platinum with an alloy of platinum and iridium or rhodium gives the best results.

Mr. Lagarde has made a re-determination of the specific resistance of pure copper, and finds it to be 19·58 ohms, presumably legal ohms, at 0° C. for a wire 1,000 metres long and one millimetre in diameter. He also found that the temperature coëfficient ·00445 is fairly constant between 0° and 40° C., and that it is directly proportional to the conductivity of the copper.

A writer in a German paper calls attention to the fact that the shape of the waves of an alternating current will have quite a perceptible effect in the reading of a voltameter and in the working of an alternate current arc light, and he concludes therefrom that both should be adjusted with currents from the same generator with which they are to be used.

A French writer has devised an analytical method for determining the shape of the curves of alternating currents, consisting of an experimental determination of the successive terms in the Fourier series, from which the curve can then be deduced. The measurements are made with auxiliary apparatus used in connection with the alternator.

There was much discussion in foreign journals regarding the work to be done by the Chicago Congress, but as all this was entirely ignored by the delegates to that Congress it may be passed over here. Although it has been of little use, it was none the less interesting and instructive.

CHARLES A. COULOMB.

By Prof. Edwin J. Houston.

[*Read before the Electrical Section of the Franklin Institute at its stated meeting, March 28, 1893.*]

The eminent services of Charles A. Coulomb to physical science generally, and to the field of electricity and magnetism in particular, have long been recognized by the scientific world. When the custom arose of naming the practical electric units after distinguished electricians or physicists who had passed from their labors, Coulomb was remembered and the practical unit of electric quantity was named after him.

Portraits of all the scientists after whom the units of electricity are named, have been published, with, I think, the exception of Coulomb.

One of my former students, a grandson of Coulomb, has loaned me a eulogy on his grandfather by Delambre. This eulogy gives an excellent account of the civil and scientific services rendered by Coulomb to the world, and I have thought that a translation of the same, together with a photograph, taken from an oil painting now in the possession of the Coulomb family, might be of interest to the electric public.

I have, therefore, made a free translation of the article. The manuscript is in that illegible handwriting so often characteristic of genius. Indeed, this is true in the present case to such an extent that in all probability I may have erred in some respects in my translation. I believe, however, that this will be true to but a limited extent, especially as Prof. Bernard Maurice, Professor of French in the Central High School of Philadelphia, has kindly given my translation the benefit of his criticisms.

Although the translation can best speak for itself, yet a brief summary of the more important of M. Coulomb's contributions to physical science may be of interest.

The field which M. Coulomb occupied in science was a

varied one. His earlier work comprised the construction of submarine works with means for laying foundations without previous drainage.

He also early in life conducted a series of investigations as to the efficiency of man as a prime mover, and made various calculations as to the amount of work that a man can do when obliged to spend his power for the driving of machinery. Later on in life he was awarded by the French Academy a prize for a theory of simple machines, and conducted an extensive series of experiments concerning the strength of materials and the friction of one body over another, either when in motion or when started from a state of more or less prolonged rest.

In connection with M. Swinden he was awarded the prize by the French Academy for the best construction of compasses.

The contribution to physical science, on which it may be said that M. Coulomb's reputation mainly rests, was the invention of the torsion balance, by means of which he conducted that extensive series of experiments in electrostatic and magnetic attractions and repulsions, which won for him a lasting reputation as an experimental philosopher of the highest type.

In the construction of the torsion balance, he established the law that the force producing the torsion of a wire is directly proportional to the angle of torsion.

It was by means of this balance that Coulomb established definitely the law that magnetic and electric attractions and repulsions between two bodies are inversely proportional to the square of the distance.

It may be of interest to the Section to note that Coulomb proposed a theory of magnetism which bears a remarkable resemblance to some of the theories of magnetism propounded during later days.

Coulomb imagined that the molecules of a magnetized bar consist of numerous separately magnetized particles, with their opposite poles in contact, and showed how the opposing actions of such poles, would, for the greater part, neutralize each other, leaving the two extreme poles alone

to act freely as centres of action at the ends of the bar. By a series of extended investigations he showed that the property of magnetism was by no means confined to iron, obtaining unequivocal signs of attraction in all of the many substances that he subjected to experiment. Nor did he ascribe this property of magnetizability to the presence of iron in the different bodies, which he found were susceptible to the magnetizing force; for, as he himself pointed out, in order to permit this supposition to be true, it would be necessary to assume so considerable a quantity of iron distributed throughout the substance, that it could not have failed to manifest itself to even ordinary chemical analysis.

Coulomb made a study of the distribution of magnetism in a magnetic needle, showing that the magnetic force is very feeble throughout nearly the entire length of the needle, but is concentrated at two points near the ends, *i.e.*, at its free poles.

It was in connection with the above studies concerning the distribution of magnetism in a needle, that Coulomb sought for an analogous distribution in an electric charge, and showed by means of his investigations that an electric charge, which is so powerful at the surface of bodies, penetrates the interior but slightly, and, at the same time, ascertained the law according to which an electric charge distributes itself over conductors of different dimensions.

His investigations also extended to the action of points on the discharge of electrified bodies.

In the domain of magnetism Coulomb constructed an improved inclination compass and proposed methods for the production of artificial magnets. He also investigated the effects which temperature produces on magnetism, calculating the temperature to which it would be necessary to heat a magnetized needle in order to deprive it entirely of its magnetism.

The brief review which I have made concerning the extended discoveries of Coulomb, when taken in connection with the translation, will, I think, show the importance of his scientific work.

The INSTITUTE of FRANCE.

ACADEMY OF SCIENCES.

The Perpetual Secretary of the Academy certifies that the following is an extract from the memoir of the Class of Mathematical and Physical Sciences of the National Institute of France, vol. 7, Second Semestre, p. 206:

HISTORICAL EULOGY of CHARLES A. COULOMB.

By M. Delambre.

[*Read at the Public Séance of the 5th of January, 1807.*]

Charles Augustus Coulomb, Lieutenant Colonel in the Engineer Corps, Chevalier of St. Louis, Member of the Academy of Sciences, and afterwards of the Institute and of the Legion of Honor, one of the Inspector Generals of Education, was born on the fourteenth day of June, 1736, at Angoulême, of a family which was distinguished in the magistracy of Montpellier.

Coming at an early age to Paris, he manifested so decided a taste for the mathematical sciences that he determined to devote himself entirely to them: but, finding some obstacles to the execution of this project, he entered the Military Engineer Corps, where he at least hoped to use for his advancement that knowledge the pursuit of which was his sole passion, and, in order to achieve more promptly the end of his ambition, he determined to go to America, where he was employed by the Government in the construction of public works of the greatest importance. Here some work undertaken during hot weather seriously affected his health. The cruel malady by which he was attacked, and which had been fatal to all his co-workers, made him desirous of returning to France. His superior officer, however, kept him in the service by the higher rank to which he raised him and by inspiring hopes which were unfortunately never realized. He finally returned to France after nine years' absence. Up to this time he had given himself unsparingly to his profession. He brought to this work, as means for carrying

out with greater economy and solidity the various constructions which he directed, that spirit of experimental research and calculation which so eminently distinguished him. The observations and theories which had guided him in such work furnished materials for a memoir which he read before the Academy of Sciences, and which secured for him the title of Corresponding Member.

About the same time he designed methods for carrying on submarine works without previous drainage, and invented a species of wheel which appeared to him similar in its operation to a windmill, and tested its efficiency by comparing the useful effect with the effect lost by blows and by friction.

We would refer to this epoch a memoir, which, however, he did not publish until twenty-five years afterwards, but which he read before the Academy in 1775. In this memoir he estimated the quantity of work which men can furnish in their daily labor, according to the manner in which they employ their strength. The aim of these researches, undertaken at different epochs of his life, was to diminish the fatigue of man when obliged to act as a simple machine.

In 1779 he shared with M. Swinden the prize offered by the Academy for the best construction of compasses. Two years afterwards he carried off the prize offered by the same society for a theory of simple machines.

Amontons had published some experiments on the same subject, but these experiments, being conducted on a small scale, in the physical laboratory, were insufficient to correctly estimate the friction of machines designed to carry great loads. The first thing to do then was to design an apparatus that could be loaded with enormous weights, which would permit of variations in the trials, of the calculation of the effects, and of the observation of the friction of different bodies, either dry or covered with unguents, sliding over one another in different directions, both while in motion, or when started from a more or less prolonged state of rest. M. Coulomb who then lived at Rochefort, found in the Marine Arsenal, by the kindness of the Commandant M. Touche Treville, everything which could facilitate this

new and important research. The Academy, in crowning this work, testified their satisfaction both as to his theory and as to his experiments.

These two researches possessed that characteristic which M. Coulomb had impressed on all his works. In the one, as in the other, we observe his close attention to the interrogation of nature and his ability to seize and verify everything of importance, to search in rational mechanics for the formulæ best suited to connect the isolated facts, and to try new experiments, and, by varying them in a suitable manner, to endeavor to determine the kind of formulæ and the quantities which could be varied according to the nature of the substances submitted to experimentation.

It has already been said of those who have distinguished themselves by the advancement of new views, that the germs of their discoveries were contained in their first work; that their later productions have been but enriched and matured developments of their earlier ideas.

We have a new proof of this saying in the labors of M. Coulomb, which are to be ranked among the most advanced in physics.

In the competition for a prize on the compass, one of his competitors indicated a means for avoiding the effects of torsion; that is to say, the resistance which the suspended wire offers by its rigidity to the force of magnetism, tending to deflect the needle in a constant direction. M. Coulomb endeavored to familiarize himself with these effects of torsion, and even described at that time an apparatus for measuring with accuracy the forces of torsion, but he could not find a mechanic capable of constructing the apparatus he had designed, and this, his first conception, announced while undeveloped, no doubt contributed in some degree to the success he afterwards achieved.

There is no little difficulty in appreciating all that is contained in these first suggestions, all that was born in this early conception.

In 1781, M. Coulomb continued his labors in Paris. The Academy was eager to admit him to membership. All his thoughts were now turned toward those researches on mag-

netism and electricity which formed both his chief glory and the richest collection of the Academy. Here he completed his successive labors and discoveries.

In order justly to appreciate the services which M. Coulomb has rendered to physics, and to understand the advantages of his methods, let us take a brief glance at the state of physical science at different epochs.

The ancients were acquainted with physics in name only. To be convinced of this fact, it will suffice for one to read, if able to do so, the numerous treatises of Aristotle, not so much on the general subject of physics, as on the heavens, generation, corruption and meteors.

We will remark that in all of these are contained numerous dissertations on space, time and the principles of the elements. What advantages can one draw from this obscure mass of unintelligible metaphysics? What can we understand in the very brief treatises in which Plutarch has rendered but poor service to the Grecian philosophers, by condensing their opinions in an exceedingly brief space as if he wished by the collection the better to turn them to ridicule?

What do we see in these treatises, unless it is that, satisfied with an insufficient examination into some phenomena of nature, the authors had been afforded an opportunity of exercising their imagination on such phenomena, without being able to invent any of those ingenious machines which aid in the investigation of nature; so that with the single exception of some of the striking truths found in the writings of Archimedes concerning his inventions, together with some other of the geometricians and mechanicians of Alexandria, amongst which we find Hiero, whose name even yet is given to an interesting machine found in all cabinets of philosophical apparatus, we would be perplexed to find in their writings any statements which could properly be inscribed in modern treatises, and, if we did mention their names it would only be to point out their errors. We see then the reason for the small progress which the ancients made in physics; they only studied it as metaphysics.

The reason they had more success in the study of astronomy was because at an early date they felt the necessity for employing suitable instruments and making observations and calculations.

The happy applications of geometry to one of the most important branches of physics pointed out the road necessary to follow in order to equally perfect all other branches. It was in fact this road which Galileo took at the epoch of the revival of letters and sciences.

It was by geometry that he discovered new and ingenious means for measuring the fall of bodies.

The pendulum, the barometer, the air pump and the prism enlarged the field of experimentation. His book of mathematical principles placed physical science on a true basis. The fact was then fully appreciated that the sciences could be perfected only in so far as they could succeed in carrying into this obscure domain the double torch of experiment and calculation.

S. Gravesende endeavored to produce a complete course of mathematical physics, but magnetism and electricity could find no place in his plan; for electricity was scarcely born and magnetism had been but little developed.

Æpinus was the first who submitted these subjects to analysis. He endeavored principally to explain known effects, but his progress was inconsiderable: for he was not sufficiently careful to verify by experiments the results which he obtained by calculation.

It was by illuminating one fact by another and by fusing them into one, that M. Coulomb reached the hitherto unknown principles with which he enriched physics.

From the first he appreciated the necessity for new apparatus. Attractions, either electric or magnetic, so powerful at exceedingly small distances, either rapidly decreased or disappeared entirely at comparatively small increase of such distances. In order to measure them correctly, it was necessary to oppose them to a known force which they could readily overcome; to employ a body so light as to permit the least force to impart to it a sufficiently great movement, under conditions ln which

exceedingly small forces could be rigorously measured. M. Coulomb hoped to find such a force in the almost imperceptible resistance a wire offers to a force tending to twist it. He ascertained that this resistance increases uniformly with the amount of torsion given to the wire, or, to speak in scientific language, that the force was proportional to the angle of torsion. He was then in possession of the instrument he so long desired, and it was by this simple means that he discovered the law which had hitherto escaped the researches of physicists.

He showed by simple and convincing experiments that the attractions and repulsions are in the inverse ratio of the square of the distance. This law was immediately adopted by all physicists, most of whom had a presentiment of its truth. Æpinus had often employed this law in some of his calculations, judging it to be the most probable that could be conceived, but he had not been able to discover the means for its demonstration. This glory was reserved for M. Coulomb.

These discoveries accomplished, by means of which he conquered two modern branches of physics, we see M. Coulomb employing the rest of his life in cultivating the domain he had conquered.

The law which he had discovered became of great assistance in his subsequent calculations and experiments. But it was not sufficient. It would be necessary to combine with it an intimate knowledge of the essential properties of that marvellous agency, the production of which we cannot yet entirely control. Æpinus explained the principal phenomena of electricity and magnetism on the assumption of the existence of a fluid, the molecules of which possessed the double property of mutually repelling one another, and of being attracted by the molecules of gross matter. But he was obliged to assign to these molecules the double property of mutually repelling one another and yet of being attracted by the molecules of other bodies, a property difficult to reconcile with generally received notions.

The hypothesis of a double electric fluid conceived by

Symmer, and employed by Wilke and Brougman, though less simple at first glance, nevertheless contains nothing inconsistent with well-known principles. In all his calculations M. Coulomb adopted this hypothesis as the best.

In order to place this hypothesis beyond all objection, and entirely to reconcile it to the phenomena of attractions and repulsions which it describes, it is very desirable that one should be able, by direct experiments, to demonstrate the existence of these two still problematical electric fluids. They are now indicated only by calculation. They can explain phenomena, but nothing yet demonstrates that it is impossible to find a simpler explanation of such phenomena.

When the early astronomers wished to account for the unequal movements of the sun they found two hypotheses equally capable of satisfying their observations. The double inequality in the movements of the planets requires the assumption of two hypotheses, either of which sufficed to account for the orbits of the very eccentric planets, such as Mars and Mercury. This system, which at first seemed so happily conceived, was afterwards set aside or reversed by Copernicus and Kepler.

One might fear, or indeed, rather desire, a similar fate for our two hypothetical fluids. Already we feel that the phenomena in question require further explanation. To avoid this difficulty, M. Coulomb supposes that all the molecules in a magnetized bar consist of so many magnetized parts, the opposite poles of which are in contact. The opposite actions of these poles should for the greater part destroy each other. The two extreme poles can alone act freely and hence form two centres of action placed at the extreme ends of the bar. No matter how ingenious this conjecture may be, it may very closely resemble the hypothesis of epicycles of the ancient astronomers, which possessed no other real merit than to facilitate calculations which will lead to the knowledge of the real causes. It is the same with the two electric fluids. It is very ingeniously assumed that the resinous and vitreous fluids experience unequal resistance in the air. Nothing prevents us from admitting hypotheses provided they are not incompatible with known principles,

only we may regard with regret the complexity of the system. But, in the midst of so many causes which act to obscure the phenomena, it is not astonishing that the explanation loses much of the simplicity that we would desire it to possess. The planets, separated from one another by immense distances and moving through free space, may rigorously follow the law which suffices to explain their almost imperceptible inequalities. But bodies which we hold in our hands, and with which we experiment, are very far from being placed under such favorable circumstances. Where many forces operate it is necessary to include them all in the calculation, so that complex effects would not be reduced to very simple principles. It is not, therefore, the fault of the physicists if their explanations are not characterized by that unity which we are accustomed to find in the problems of astronomy.

But if physicists are thus placed at disadvantages they are recompensed by other considerations which should animate them with courage.

The heavenly bodies revolving at such vast distances from us, only complete their revolutions in times that are more or less considerable, but always very long, and it is only at great intervals that they can come into conditions favorable for the researches of those who wish to explain their movements. The physicist, on the contrary, holds in his hands the objects of his study. He can at will place them in suitable positions, and, if astronomy has required centuries to perfect itself, we can hope that in much less time physicists will be able to reach that certainty and clearness which may reasonably be expected.

Such progress will ultimately crown the work of those, who like M. Coulomb, have not only endeavored to create new apparatus for new research, but who also avail themselves of the infinite resources that may be found in modern analysis.

By means of the torsion balance, which permitted him to measure the feeblest manifestation of magnetism and electricity, he satisfactorily determined the law according to which electricity passes and insensibly disappears, the influ-

ence which produces the effect, the humidity of the air which surrounds the conductor, and the imperfection of the supports by which they are insulated. He showed by delicate experiments that electricity, which is so powerful at the surface of bodies, becomes insensible when we penetrate the interior but slightly, and that magnetism, very feeble through almost the entire length of the needle, possesses strength in but two points near the ends, and sought to discover the law according to which electricity distributes itself along conductors or on globes of different dimensions. What can be the cause of the power possessed by points and the great effect of the electric kite (*cerf volant électrique*). From these difficult speculations, so pleasing to him, he descends to objects of practical utility. It was to obtain a better construction for the compass that he had undertaken his early researches. In proportion as he made sensible progress he endeavored to improve his more important instruments, as, for example, the inclination compass. At this time more or less complete means for producing artificial magnets were in use. By the application of his theory M. Coulomb was enabled to add increased perfection to the best of these methods.

As regards the influence of temperature on magnetism, viz: that the strength of magnetism decreases as the heat increases, he found by very convincing experiments and by the aid of a theorem of M. La Place that it would be neces sary to give a needle 700° of heat in order to deprive it entirely of its magnetism.

For a long time iron had been regarded as the only body which is attracted by the magnet. M. Coulomb found some unequivocal signs of attraction in all the bodies he subjected to experiment, from which he believed that he could conclude that magnetism like electricity occurs throughout nature.

This discovery is the last he made. The task of verifying it kept him occupied up to his last moments. We find in his manuscripts some curious experiments from which it would appear that in order to attribute to iron hid in different bodies the degree of magnetism which he had observed,

we must assume that there exists uniformly spread throughout these substances a quantity of iron so considerable that it would not have failed to manifest itself under the investigations of any distinguished chemist who had undertaken to separate or purify the substances on which he had made his experiments. We shall not now study in detail Coulomb's unpublished researches. These cannot yet be properly judged by savants. We feel that this is not the place to give an extensive idea of his works. Besides, such an exposition already exists. All savants can read it in the best and most modern treatises on physics. Coulomb ranks among the first physicists of Europe. He has distinguished himself by creating a new branch of natural science and has presented in the clearest and most methodical manner all the discoveries and theories of his distinguished contemporaries. This extract, which may serve in some respects as a commentary on the doctrine of M. Coulomb, does not prevent us, however, from having recourse to the original writings for a multitude of details necessary for those who may wish to continue the work that was so sadly interrupted by his death.

For a long time it was hoped that M. Coulomb would collect in a complete treatise, in the order in which he had discovered and demonstrated them, the ideas which he had published in his numerous memoirs. His friends often asked for such a work, but the feeble state of his health gave him little hope of its completion. He preferred to add as much as he could to the sum of our knowledge. He left for the bookseller, who was to print the collection, a note as to the order in which he wished his memoirs arranged. Before beginning the printing, it will be necessary to examine his manuscripts, and to transcribe the notes which he added to them, for this will form an interesting sequel to the material which he has himself published.

We have so far presented M. Coulomb as a very distinguished savant. The man himself, however, was no less deserving of commendation; that good sense, that uprightness and severity of principle, which he manifested in all his mathematical researches, were no less strongly evinced in his moral conduct.

Sent to Brittany by the Minister of the Navy, as a Commissioner of the King, to examine some projected canals, he employed all his energy to prevent the adoption of ruinous plans. The province, recognizing that it could not induce him to accept any other mark of its gratitude, bestowed upon him a testimonial, which possessed in his eyes no other merit than that of often recalling to him the recollection of the services he had rendered and of the esteem he had gained. When the revolution came, he resigned all his public positions, among which was that of General Superintendent of the Water Supplies of France and Superintendent of the Fortifications. The first was hereditary in his very distinguished family and would otherwise have passed to his descendants.

Thus relieved of his labors he occupied himself in collecting the remnant of his fortune, of which he was able to save only a very small part. He hoped to find consolation in the Academy and in the continuation of his labors; but the Academy was suppressed. He retained his membership in the Commission of Weights and Measures, but was cut off from this shortly afterwards, and, being obliged to leave Paris by the law which expelled all the nobility, he retired with his friend Borda, to a country seat which he owned, in the neighborhood of Blois.

In this solitude, in the bosom of his family, and with the consolation of friendship, M. Coulomb almost changed the manner of his life. He was able still to continue his meditations, which he even extended to new objects. The vegetable world claimed his attention. Some trees he had cut down gave him ideas on the motion of the sap. He began some researches on plants, and the fragmentary notes on these subjects which we find in some of his manuscripts, make us wish that the remainder was accessible.

Recalled from exile to continue his labors on weights and measures, we find him at this work for but a few days. He was anxious to return to his wife and children and to take care of the little property which was now their sole resource.

He returned to Paris only on the re-establishment of the

Institute. His health, which had been impaired, made it necessary for him to seek that medical aid which he had so long refused. An excessively nervous temperament gave him vivacity of character, coupled with a certain impatience, from which however, owing to his constant endeavor to conquer it, he alone suffered.

Named as an Inspector General of Instruction, although he might have regarded this favor as an indemnification for his many losses, and although by reason of his varied knowledge in different branches of public instruction, he was as well qualified as any person for so important a post, yet he hesitated a long time as to whether he should accept it.

He feared fatigue that would injure his health, as well as protracted absence that would interrupt works in which it would be difficult to find a substitute. He had devoted himself to developing the character of a son, who already responded to his care and whom he would now be obliged to place in other hands. He however, accepted the position offered, Madame Coulomb now became his inseparable companion in all his work. Thanks to her care and to her active tenderness, he escaped the dangers he had feared from his public labors.

M. Coulomb gave himself up to his new duties with all the zeal and precision which characterized him. His grave and severe countenance was softened by the presence of young children, who recalled to his paternal heart its sweetest delight. He sp[illegible] to them as a father to his children; aided them in their weaknesses and encouraged them in their timidity. He loved to find, in their growing character, promises of talent which might eventually be of use to his country. Only those who have seen him in private life can properly testify to the charm and abandon of his nature. Faithful husband, kind brother, good father and friend, man of integrity and devoted citizen, he exercised all virtue spontaneously and without ostentation; severe to himself but indulgent toward others. His manner exhibited that ease which comported so well with the gravity of his character, but which could not suppress his

sweet and quiet gaiety which was that of a soul at peace with itself. Noble and generous in all his affairs, he occupied himself least of all with his own interests.

Although modest and unpretentious, he knew how to repel an unjust attack with both strength and dignity. This last trait of his character he had but little occasion to develop. In the one case which comes to our knowledge, and which the Institute has not forgotten, his adversary who did not know that he was attacking M. Coulomb, afterward admitted his own error.

No one enjoyed more general consideration. He had seen his doctrine admitted and taught by the most distinguished scientific men. The world was pleased to render him justice. His merit and his success never made him an enemy. He longed for nothing but better health. His condition, for a long time before his death, gave his friends much uneasiness. A grave chronic infirmity, which he himself regarded as the forerunner of approaching death, was added a slow fever which gradually consumed him.

The feeble condition to which he was reduced, forbade him taking any nourishment; and all resources of art, administered by hands of friendship, were found equally powerless to mitigate his suffering or to revive his failing strength. He died on the twenty-third of August, 1806, leaving to his son no other inheritance than his honored name, the example of his virtues and the memory of the important services which he had rendered to the world.

His place in the Academy was filled by M Montgolfier.

Certified and confirmed by the Perpetual Secretary of the Section of Science and Mathematics. F. ARAGO.

[*Proceedings of the stated meeting, held Tuesday, November 28, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 28, 1893.

ELMER G. WILLYOUNG, President, in the chair.

The stated meeting of the Section was called to order by the President.

The minutes of the preceding two meetings were read and approved.

The Treasurer reported $29.14 on hand, and presented bills for postage, printing, etc., amounting to $23.46, which were ordered paid.

The names of Prof. Jos. O. Thompson, Haverford, Pa; W. Hoopes, Cynwyd, Pa.; J. Appleton, 1007 Spruce Street, Philadelphia; John Brackin, Central Manual Training School, Philadelphia; Theodore B. Lewis, 2025 Pine Street, were proposed for membership and referred to the Committee on Admissions.

A motion was read, to be submitted at the next regular meeting, to amend section 1, article vi, of the by-laws, by striking it out and substituting the following:

Immediately following the annual election of officers, the President shall appoint two members who, with the President, shall constitute a Finance Committee.

This committee shall examine all bills, and such bills, when approved by them and signed by the President, shall be paid by the Treasurer.

In the absence of the President, the chairman of the meeting shall have power to act for him.

Thomas Spencer and P. A. Mitchell were appointed by the President to audit the accounts of the Treasurer.

The following nominations were made for officers of the Section for 1894: For President, E. G. Willyoung; Vice-Presidents, Carl Hering and Prof. E. J. Houston; Secretary and Treasurer, Robert H. Laird; Conservator, Dr. Wm. H. Wahl. Upon motion, the Secretary was authorized to issue tickets for the proposed course of lectures. A motion was also made and carried that the Section assume the expenses pertaining to the lectures.

Adjourned. R. H. LAIRD, *Secretary.*

[*Proceedings of the stated meeting, held Tuesday, December 26, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 26, 1893.

ELMER G. WILLYOUNG, President, in the chair.

The stated meeting of the Section was called to order by President Willyoung.

The minutes of the meeting of November 28th were read and approved.

A motion was also made and carried that the Secretary cast the ballot of the Section for the officers nominated at the regular meeting of November 28th. Upon motion, the further business of the evening was suspended. The President then introduced Prof. H. S. Carhart, of Ann Arbor, Mich., who read a paper on "The Theory and Design of the Closed Coil Constant Current Arc Dynamo."

Adjourned. R. H. LAIRD, *Secretary.*

THE THEORY AND DESIGN OF THE CLOSED-COIL CONSTANT CURRENT DYNAMO.

BY HENRY S. CARHART.

[*A lecture delivered before the Electrical Section, December 26, 1893.*]

Constant current dynamos for arc lighting have been in practical use for the past fifteen years. Most of the public lighting by arc light service has been done with dynamos of the open-coil type. They secured the field at an early day in the development of this branch of electrical industry through the inventive genius of Mr. Charles F. Brush and the splendid ability of his business associates. This success was repeated a little later by the equally brilliant achievements of Professors Thomson and Houston and the phenomenal management of the company formed to exploit their patents. Aside from any question of inferiority, it is therefore easy to see why the closed-coil dynamo for constant currents has remained so long in the background. It has not received the attention to which it is justly entitled, and has not been investigated with the thoroughness and skill which it merits. It is not my purpose to draw any comparisons whatever between open- and closed-coil armatures. The former is entitled to that consideration which long-continued and satisfactory service in public and private illumination has earned for it. But the latter is making its way into public favor, and it has certain peculiarities which make it an interesting subject for study. If I were to draw attention in this paper to comparisons between dynamos of different types, it would be between those for constant potential and those designed for constant current, both with closed-coil armatures. For in almost every particular the latter is diametrically opposite to the former. The one is designed to give a constant potential; the other a constant current. One is shunt or compound wound; the other series wound. In the one the resistance of the armature is as low as possible in comparison with the field; in the other

the armature resistance is relatively large compared with t field. The one has a sensitive field and is worked below t saturation point; the other should have a stable field whi is worked well up on the saturation part of the curve magnetization. Ideally the characteristic of the one is horizontal line; that of the other a vertical line. In th constant potential machine the brushes are set only slight in advance of the theoretical neutral line or plane; in th constant current dynamo the brushes may be at any poin on the commutator according to the load, while the neutra plane remains fixed. When the load decreases with the on the brushes if moved at all are rocked backward for spar less commutation; when the load decreases with the othe the brushes are rocked forward for minimum sparking o even sparkless commutation and constancy of current. When the load increases on the one it governs by an increase of induction from an increasing field; when th load increases on the other it governs by decreasing th counter electro-motive force in the coils between the brushes and the neutral plane. In the one armature reaction is purposely reduced to the smallest dimensions; in the othe it is purposely made of considerable dimensions. In thes comparisons it is assumed that the speed is constant in bot cases. If some of these statements are not self-evident, they will be supported, I hope, by subsequent portions of this paper.

THE NEUTRAL PLANE INDEPENDENT OF THE PLANE OF COMMUTATION.

By neutral plane is meant a plane passing through th axis of the armature and so situated with reference to th poles of the field magnet, that when a coil of the revolving armature is carried across it the electro-motive force gene-rated changes direction. This plane intersects the armature in a straight line, but it may broaden out more or less into a surface of small lateral dimensions.

The plane of commutation is a plane passing through the armature axis and the points of contact of the brushes on the commutator. It is the plane joining the poles of the

armature considered as an electro-magnet. This latter plane of course shifts with the brushes, since the poles of the armature are the points at which the current enters and leaves the armature, and these are necessarily the points or surfaces of contact of the brushes with the commutator, assuming that the connections from the armature to the commutator run directly out parallel to the shaft. To state the proposition now under discussion in the form of a question, does the neutral plane shift when the brushes are shifted forward or backward? If we were to make answer from the assumption that the resultant of two impressed magnetizations or magneto-motive forces may be obtained in the same manner as the resultant of two forces by means of the triangle of forces, we should probably conclude that the neutral plane rotates forward with a forward movement of the brushes. But experiment along several different lines shows that this conclusion is in error. If we were to apply to the solution of this problem the principles derived from constant potential machines we should be forced to the conclusion that, to maintain sparkless commutation at the brushes, the lead of the brushes beyond the neutral plane should be constant, since the current remains constant; and therefore that any attempt to govern for constant current by rocking the brushes must be attended by destructive sparking, unless at the same time the field is greatly modified. But these conclusions are also erroneous. We must therefore first establish the facts and then make a theory to fit them.

The fixed position of the neutral plane I have determined on a ten-light machine in two different ways.

First Method.—Four turns of No. 16 silk-covered magnet wire were wound around the armature ring as an exploring coil. One end of this coil was soldered to a copper band or ring fastened on the commutator and insulated from it by several thicknesses of mica. The other end was soldered to a piece of brass let into a fibre collar placed round the commutator. One extra brush was fastened to one of the main brush holders and rested on the copper band. The other extra brush rested on the fibre collar and could be

attached to any point of a circular scale made concentric with the commutator. A twisted cord ran from these two brushes to a telephone at some distance. When the dynamo was running the movable brush, which rested on the fibre and made contact with the brass strip every revolution, was moved round the circle till a minimum sound was heard in the telephone. The exploring coil was then on the neutral plane at the instant when the brush made contact with the strip. Motion of the brush either way caused the sound to increase in loudness. The position of the exploring coil for minimum sound was found to be about 5° in advance of the normal plane intermediate between the pole pieces; and its position did not change from full load to no load as far as could be detected by this method.

Second Method.—To the brush holders was attached an insulating ring slotted on the periphery at every 10° on a milling machine. It was made as nearly concentric with the commutator as posssible. A third brush holder was placed in the successive slots, and the potential difference between it and one main brush was measured in its several positions. These measurements gave the integrated potential difference between the main brush and successive points on the commutator all the way round the circle and back to the starting point. This was done with no load or nearly short-circuit, with a load equivalent to three lamps, and finally with a load equivalent to nine lamps, the current being ten ampères in each case. The results in the first two cases are plotted round a circle in *Fig. 1.* Positive values, or those in which the potential of the third brush was higher than that of the main positive brush, are set off outside the circle in the upper part of the figure; while negative values are set off outside in the lower section of the diagram. The direction of rotation is clockwise. With no load the highest positive potential was about 78° behind the positive brush. From this point it fell again, and at 128° it was the same as that of the positive brush. For all the coils between 0° and 128° the integrated positive and negative electro-motive forces exactly equal each other.

The neutral plane falls evidently 78° behind the brush, or the brushes may be said to have a lead of 78°, with no increase in sparking. A negative maximum occurred at about 260°, and the potential difference between the positive and negative maxima was 644 volts. The same poten-

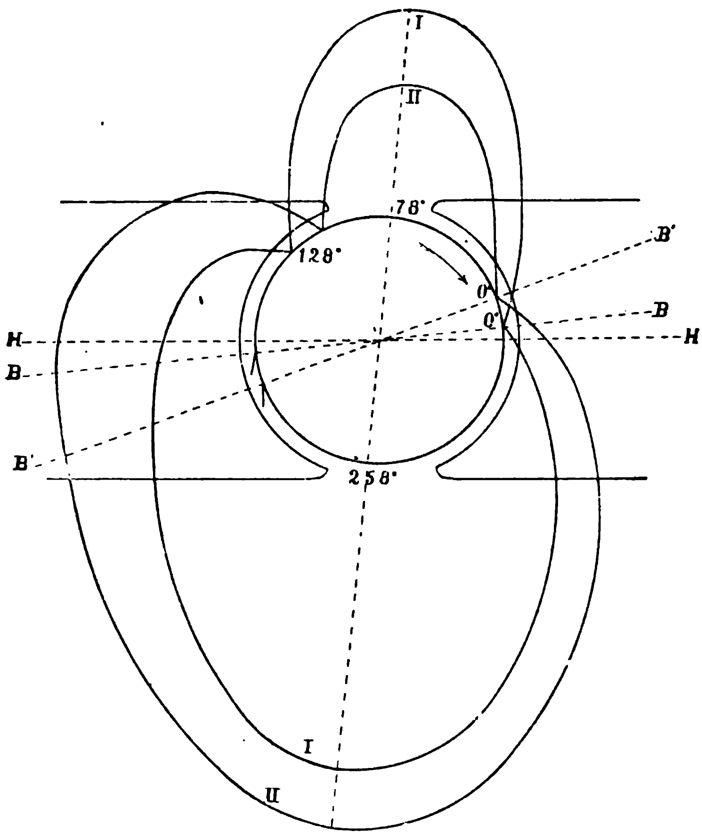


FIG. 1.

tial difference was found by direct measurement when two extra brushes were set at these points.

With a load equivalent to three lamps the brushes were rocked back 15° to bring the current to ten ampères. Hence, the zero of this curve begins 15° back from the zero of the first curve. Again, the observations are plotted

and the positive maximum falls at the same place on the circle, and, therefore, at the same place on the commutator. The two maximum points are at about 65° and 245° from the positive brush and the two potential differences are 168 and 456 volts. Their sum this time is 624 volts, a little less than with no load. With the highest load carried the brushes were rocked backward about 50° further and the lead was then about 15°. The extreme potential difference obtainable this time did not exceed 600 volts. So far as can be discovered from these curves the neutral plane remains fixed, while the brushes move round the commutator to adjust to a constant current. I find no evidence in them that the forward movement of the brushes to control the current causes the neutral plane to move with them. As the brushes advance with a diminishing external load they put between them and the neutral plane an increasing number of armature-turns generating counter electromotive force; and it is a striking fact that, when the field coils are not cut out, the back-turns on the armature cut down the potential difference between the brushes not by a counter magneto-motive force apparently, but by counter electro-motive force; for the maximum potential difference to be found on the commutator is no less on no load than on full load, showing that at least as many lines of force traverse the armature core with the brushes far forward and with many back armature-turns as with the brushes in the position for maximum load and with the back-turns reduced to a minimum.

THREE METHODS OF GOVERNING.

Assuming still practically constant speed, we next inquire into the methods employed to maintain a constant current without appreciable sparking by rocking the brushes round the commutator cylinder.

In one machine the brushes are moved automatically by means of a small electric motor and at the same time field coils are successively cut out as the brushes rock forward with a light load. A pair of brushes is used on each side and they are kept at a fixed distance apart. By these com-

bined means the machine can be run on short-circuit with the normal current and without sparking.

Another system leaves the field coils constantly in circuit, but employs two pairs of brushes and varies the angular distance between the members of each pair when the brushes are moved. The movement of the brushes is effected mechanically in response to any change in the main current till the current is brought back to the normal value. In these machines the spread of each pair of brushes, or what is sometimes called the overlap of the brushes, is lessened as they rock forward toward the polar centres. Very satisfactory results are secured in this way.

In the third class of machines only one pair of brushes is used, which lap over about two or three commutator sections, and the regulation of the current is effected solely by the movement of this one pair without change of overlap and without disturbance of the ampère-turns on the field. The brushes are moved mechanically by means of an automatic regulating device. No less satisfactory results appear to be secured by this method than by the others, while the mechanism as a whole is somewhat simpler.

I have described these three methods for the purpose of pointing out their bearing on the theory and design of closed-coil Gramme rings for constant currents. The important question is not how to get the necessary electro-motive force with such a dynamo, but how to vary that electro-motive force in response to the varying demands of the external circuit, without injurious sparking at the brushes.

The electro-motive force is controlled in all three of these methods by rocking the brushes and the other differences in the devices are made necessary for the suppression of the sparking. This brings us to a consideration of the most intrinsically interesting topic of the paper, viz: the conditions necessary to suppress sparking and the features of design required to furnish them.

SUPPRESSION OF SPARKING.

If we assume that the armature is well balanced electrically and magnetically and that the brushes have a

proper bearing in contact with a smooth commutator, the conditions required to commute the current without sparking are known to be as follows: With a two-pole dynamo, the current is divided through the armature, one-half going from brush to brush through one side, and the other half through the other. Hence, when an armature coil is carried past the brush it is transferred from the one circuit through the armature to the other, and at the same time the current through it reverses its direction. This constitutes the act of commutation. But the sudden decay of a current through a coil in one direction and its growth to an equal value in the other gives rise to an electro-motive force of self-induction opposing the change. This electro-motive force will prolong the flow of the current on one side of the brush and will oppose its rise on the other side. Hence, if the coil is short-circuited by the brush lapping over the two consecutive commutator segments to which its ends are connected, even when the coil passes the neutral plane of the dynamo, the electro-motive force of self-induction produces a local current through this coil; and when the one end of the coil slips past the brush and becomes a part of the other half of the divided circuit the current which should reverse through it meets the opposing current and breaks over the gap to the brush with a spark. Hence, the commutation must not take place at the neutral plane but in advance of it, and in a field where the induced electro-motive force in the coil shall be just sufficient to offset the self-induction and in addition shall reverse the current in the coil while it is passing the brush or pair of brushes, and cause it to grow to the normal value at the instant when one end of it passes out from under the brush. The induction from the field must be sufficient to bring the one current to zero and to set an opposite one of equal value flowing in the coil, during the time it is under the brush. Then the commutation will be sparkless.

Now, if the current is kept constant in strength the field induction required to accomplish the results described is approximately the same whether the coil is short-circuited at one angle or another in advance of the neutral plane. It

would appear at first thought that, unless the induction in every part of the field from the neutral plane to a point nearly 90° in advance of it is substantially uniform terrific sparking must result when the brushes are shifted far forward to vary the electric pressure to suit the requirements of the circuit; for if the induction is in excess of the requirements to accomplish the result described in the commuted coil then a current will circulate through it during the short-circuit, and the rupture of this on leaving the brush will cause sparking. I have illustrated this action in the following manner: Separately excite the field magnets of a machine, which can run on short-circuit even with a forward displacement of the brushes without sparking. Then leaving the armature on open circuit, rock the brushes forward; the sparking will increase with each advance till it becomes terrific and endangers the machine. The induction to which each coil is subjected in an excited field produces a large current in it while it is under the brush, since there is less self-induction in the coil to offset the induction from the field than there is when the machine is self-excited and working in the normal way. There is another reason to be described later.

Considerations of this kind have led some writers to say that sparkless commutation for any position of the brushes can be accomplished only when the induction in the field is made uniform. The Statter constant current machine in England is made on this principle. Portions of the pole pieces are laboriously cut away at such points as to make the density of the lines of force entering the armature over a given angle equal. Of course, a machine built in this way will permit of shifting the brushes through a considerable angle in order to vary the potential difference without introducing sparking.

But while a uniform field accomplishes the result, no such uniformity is required; the same result may be secured in other ways. The first method already described weakens the field when the brushes move forward by cutting out ampère-turns in the field magnets. This reduces the induction to the proper amount at each point without

changing the overlap of the brushes. It is made necessary by the very high saturation of the armature core in this machine. It has the advantage of greater economy with small loads because field resistance is cut out, but it requires a more complex arrangement of parts on the machine than suffices for the mere movement of the brushes.

The second method diminishes the overlap of the brushes as they are rocked forward. In the first place this has the effect of diminishing the time allowed for the reversal of the current, but it also diminishes the number of turns of wire in the coil or coils included between the two parts of each brush. The curtailed time interval increases the self-induction of each convolution of wire because it increases the rate of change of the current in the coil undergoing commutation; but this increase is counterbalanced by the diminution in the number of turns of wire short-circuited by the brush. Hence, the total self-induction during commutation remains not far from constant. When the brushes shift forward into a denser field, however, the diminution in the overlap decreases the number of turns of wire included between the pair of brushes composing either the positive or the negative, and so cuts down the total field induction in those coils during commutation to the amount required to suppress sparking. The overlap of the brushes must therefore be inversely as the induction in a coil under the brush in different parts of the field, for the presence of the pole of the armature at any point reduces the induction. This point is a complicated one and needs further experimental study.

But in the third class of machines the overlap of the brush is constant, and the field is not weakened by cutting out coils on small load. Neither are the pole faces cut away to produce uniform induction. Attention is given to the thickness of the pole pieces so as to avoid unnecessary crowding of the lines of force toward the central portions. It is also desirable to avoid thinning of the polar horns lest they become saturated. In the old Sperry machine, which I have investigated quite carefully, each pole piece is cut quite in two. In fact, as is well known, the field has four

cores. At the same time the horns or pole tips are rather blunt. But this machine shows the violent sparking when separately excited, when the brushes are far forward and the circuit through the armature is open. The induction round the armature is not uniform, but the sparking is small for any position of the brushes with the normal current. The brush bears on about three commutator segments. I refer to this machine as an illustration of the class, and not as a model of excellence. It is no longer built.

In this machine the induction to which a coil is subjected near the brush is not the same in different parts of the field, but diminishes as the brushes are rocked forward, the current being kept constant. With the exploring coil before described and the two extra brushes bearing on the insulated copper ring and the fibre collar with brass segment, respectively, the external circuit connecting the two small brushes was carried through a d'Arsonval galvanometer in shunt. The two extra brushes were attached to the two main brush holders, but were insulated therefrom. With the one making contact with the small brass segment two and then three commutator bars in advance of the upper main brush, the following deflections were obtained with the galvanometer from maximum to minimum load, the steps being about equal.

Deflections.	
Two Segments.	*Three Segments.*
26	63·5
24	56
22	49
20	41
18	34
16·5	32
13·5	
12·5	28
10·5	

The steps were not the same in the two series of observations. No trouble was found in obtaining a steady deflection of the galvanometer, the dynamo making about 1,200 revolutions per minute. The exploring coil was therefore

subject to a diminishing induction near the brush as it moved forward with the brush toward the centre of the polar surfaces.

A similar series of experiments, made on an old Gramme machine of 3,000 or 4,000 watts capacity, built at the University of Michigan in 1876–77, gave a different result. The measurements were made by simply connecting a third brush to the upper brush holder and measuring the potential difference between it and the main brush in different parts of the field. The actual induction to which the armature wire is subjected in different parts of the field and at the same distance of two commutator bars from the main brush is thus measured.

The following table contains one series of observations:

Number of Observations.	Current in Ampères.	Potential Difference between Main Brushes.	Potential Difference between Main and Third Brush.
1	9·5	191	4·9
2	9·5	170	5·4
3	9·5	145	5·5
4	9·5	127	6·2
5	9·5	111	6·5
6	9·5	77	7·7
7	9·5	62	7·8
8	9·5	54	7·7
9	9·5	47	7·4

In this case the induction increases throughout the larger extent of the movement of the brush. But in this machine the knee of the characteristic curve is reached at about 13 ampères, while in the other machine it is found at seven ampères. The armature reaction in this older machine when run at ten ampères is relatively less than in the other one run with the same current. This is further evident from the fact that with the old Gramme run at ten ampères an increase in the current, due to lessening the external resistance, is always accompanied by an increase in the potential difference between the main and the third brush; while

with the ten-light Sperry machine, and others with similarly saturated field, an increase in the current when the brushes are fixed decreases the potential difference between the main and extra third brush. The reason is this: if the field is saturated, but not the armature, an increase in the current does not appreciably increase the field, but it does increase the armature reaction, and so cuts down the total potential difference between the main brushes as well as between one main and a third brush; while with an unsaturated field and a magnetically weaker armature, an increment of the main current produces a greater increment in

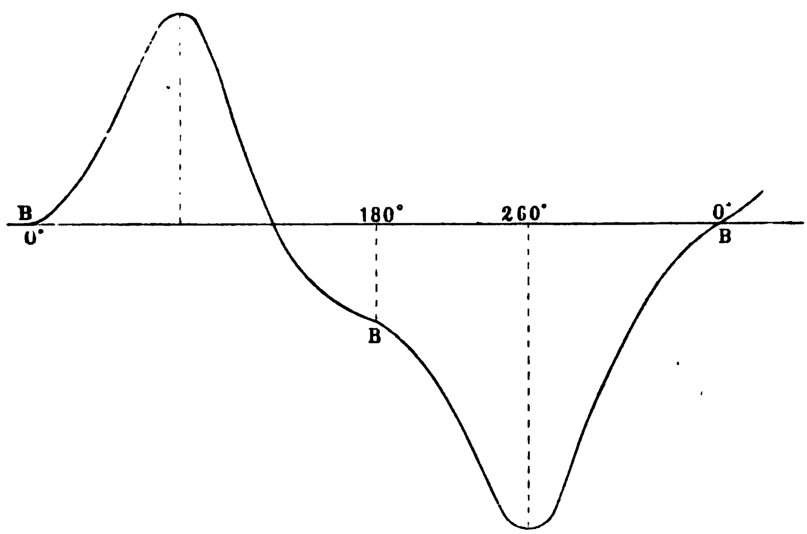


FIG. 2.

the field than in the armature reaction. With the same old Gramme machine run at about eighteen ampères, an increment in the current produces a decrease in the potential difference both between the main brushes and the main and third brush. The armature reaction then becomes relatively larger than the increase in the field magnetism. But this old machine exhibits perfectly the property of governing by rocking forward the brushes on a diminishing load, with no more sparking in one position of the brushes than in another.

Hence it is clear that for practically sparkless commutation it is not necessary that the induction *near* but *under* the brush shall be a constant. The effective means by which. with constant current, the brushes can be set in any plane round the commutator cylinder is the reactive effect of the armature. This fact is brought out quite clearly by plotting the integrated potential differences between the upper or positive brush and the third movable one as ordinates to a horizontal line. The data are the same as were employed to plot the first curve in *Fig. 1*. If *Fig. 2* is examined a decided flattening in the curve will be found at 180°, the position of the negative brush. The same flattening may be seen at 0°. All curves plotted with data obtained at different loads show the same diminution or stay of the inductive process near the poles of the armature. The armature at these points paralyzes the field. As the poles of the armature move around they sweep away the lines of force of the field, and only enough remain to produce an electro-motive force competent to offset the electro-motive force of self-induction and in addition cause the newly directed current to grow to its normal value as the coil passes out from under the brush.

This reactive power of the armature may be utilized to effect approximate regulation for constant current without brush-shifting. But for this purpose the load cannot be a maximum. The poles of the armature must be far enough forward to produce increase of magnetic leakage. As an example of what I mean, a forty-light machine had its brushes locked in such a position that it maintained thirty lights with ten ampères current. Ten lights were then cut off, and then ten more, with but small increase of sparking, and the ammeter showed an increase of current from ten to twelve ampères only. A change of two ampères is within limits possible for practical lighting. The machine was then completely short-circuited by placing a large bar of iron across its terminals without dangerous sparking. This means that the characteristic of the machine beyond the crown of the curve approached a vertical line, the ideal characteristic of an automatic constant current dynamo.

The conditions requisite for sparkless commutation of a constant current machine are therefore quite clearly defined. The self-induction of the short-circuited coils must nearly balance the field in all positions of the brushes. Both Mr. Esson in a paper before the British Institute of Electrical Engineers,* and Professor Ryan in a paper before the American Institute of Electrical Engineers,† lay down the conditions that the brushes must be kept under the pole faces in order not to enter the weakened field between the pole corners. And yet I have seen constant current machines working with the brushes beyond the extreme tips of the poles with no increase of sparking. I do not regard this condition as absolutely essential, since at maximum electro motive force the brushes may be moved through a considerable angle without appreciable change in sparking.

Professor Ryan states, in his paper above referred to, that "the magnetizing force impressed by the field ampère-turns must be uniform at all points between the pole faces." This condition is favorable to sparkless commutation, but not essential. It has to do with the area of the sparkless position of the brushes for any given load. If the field is fairly uniform this area will be about the same in different parts of the polar faces; if the field is far from uniform sparkless commutation may yet be secured, but a smaller variation in the current will produce sparking than when the field is uniform, for the sparkless area on either side of the brush with a given external resistance is then much reduced. The region controlled by the armature poles is more limited in extent than when the field is uniform.

It follows that the single magnet type of field is not suitable for a constant current machine. This fact was remarked upon by Mr. Esson. For a two-pole machine the double magnet type is to be preferred. If then the iron is reduced at the back opposite the middle of the polar surfaces and the poles are thickened and rounded off rather blunt at the ends to prevent saturation, the field induction will be suffi-

* *London Electrician*, March 21, 1890.

† *Proceedings*, Vol. VIII, p. 465.

ciently uniform without the necessity of resorting to the chopping away process applied to an English single magnet machine, described in Slingo & Brooker's *Electrical Engineering.*

Quoting again from Professor Ryan: "the air-gap is made of such a depth that the ampère-turns required to set up the magnetization through the armature, without current, and for the production of the highest electro-motive force that the machine will be called on to give, shall be a little more than the armature ampère-turns when it furnishes its normal current. Then as long as the brushes are kept under the pole faces, the non-sparking point will be wherever the brushes are placed. This will be the case whether the armature is or is not saturated." Again, "the impressed field ampère-turns are in excess of the armature ampère-turns by that amount which is just sufficient to produce a weak positive field that will reverse the current in the coil when its terminal bars at the commutator pass under the brush." This latter statement appears to be borne out by the data given, but the machine experimented upon was one giving a maximum of only thirty-five volts and twenty-two ampères, and its performance can scarcely be considered a sufficient guide for the design of machines required to furnish several thousand volts and a current of from 9·5 to ten ampères. Again, I have known a forty-light machine converted into a fifty-light without any change in the field whatever. The armature either contained more iron or was wound with a larger number of turns of wire. Both methods have been followed without effect on the sparking. The first method leaves the armature ampère-turns the same; the second increases them twenty-five per cent. If the relation pointed out by Professor Ryan holds in the first armature it cannot also hold in the second with such a material increase in armature-turns.

Further, if this relation does hold there still remains unanswered the question of relative cross-section of iron in armature and field. Shall the core of the armature be saturated or not? Mr. Esson says that 17,000 lines per square centimeter is the best practice in England for constant potential machines.

I know of one constant current machine in which the armature core is forced well up toward the highest saturation obtainable in a dynamo machine. It is able to produce very high electro-motive force, but it does not govern sparklessly by means of a single pair of brushes. Two other types of machine of which I have data work with about 11,000 lines per square centimeter in the armature. In both of these recent changes are along the line of increasing iron and decreasing copper in the armature. I have explicity advised the use of more iron in the armature for two years. One manufacturer recently told me that he is now following my advice with most gratifying results. With the same number of turns on the armature the output is greatly increased. To what extent the iron in the armature can be increased is an open question. It has now been carried beyond a cross-section equal to seventy-five per cent. of the wrought iron in the field cores. If increased cross-section of the core introduces sparking, this can be avoided by increasing the number of bars on the commutator so as to decrease the self-induction in the section under short-circuit by the brush. Indeed, if the output is kept the same, increase of iron decreases turns of wire, and to that extent decreases self-induction. In a machine with two pairs of brushes the effect is to diminish the angular embrace of each pair.

It is interesting to compare two machines of almost exactly the same capacity, but differing widely in relative core section and armature-turns. Let the two machines be represented by A and B. The data of the two are given in the following table :

Machine.	Total Volts.	Revolutions per Minute.	Segments in Commutator.	Turns per Segment.	Total Turns.	Cross-section of Iron. Square Inch	Lines per Square Inch.
A, ...	2,900	1,000	132	36	4,752	265	70,800
B, ...	2,800	875	120	72	8,640	14	79,000

The maximum number of lines of force running through the armature of the A machine is 3,650,000; of the B

machine, 2,213,000. The two machines are designed for the same current of a little under ten ampères. The ratio of the ampère-turns on the armatures of the two is nearly inversely as the cross-section of their iron cores. The ampère-turns on the B armature is eighty-two per cent. greater than on the A armature. It is not probable that the field ampère-turns on B is eighty-two per cent. in excess of those on A. Unfortunately, those particular data are lacking, but the magnetic circuit of A is quite as good as that of B. It does not appear at all probable, therefore, that Professor Ryan's rule applies to both machines.

It is gratifying to our national pride that American designers have successfully carried the Gramme ring constant current dynamo to an output far beyond what some foreign electricians with more theory and less practice in this direction still declare to be impracticable. The writer of a series of articles, now running in the London *Electrical Review*,* says: "beyond about 1,000 volts it is found, in general, to be impracticable to work a closed-coil armature; for either there will be a wasteful lead, or there will be vicious sparking under the brushes, or the current will flash from strip to strip, and will destroy the commutator." * * * "It seems more than probable that machines of that kind will not stand any serious alteration of load if worked at higher voltages, owing to the great range of lead which would be required, and the consequent sparking and flashing over." Again he says: "there is of necessity a large armature reaction in certain forms of arc light machines; and when this is the case, the brushes would require to be shifted right into the centre of the pole arc before sparking would cease, if there were very many turns on each section. The wastefulness of this practice consists in the large number of back-turns and cross-turns which it involves." But in the face of such declarations as these a large number of American machines are now running at an output of 9·6 ampères and from 5,000 to 10,000 volts. A very considerable number of closed-coil

* *Electrical Review*, August 25, 1893.

Gramme rings giving 5,000 volts are in actual use without breakdown, and without any of the fatal drawbacks predicted by the writer quoted.

The design of closed coil Gramme rings for high potential arc lighting has thus far been limited to the two-pole type of field magnet. This involves the maintenance of higher speed than engineers find desirable. The conditions of present practice and the requirements for the immediate future demand a new departure in this class of dynamo design. All indications point toward a multipolar machine of about fifty kilo-watts capacity and slow speed. The armature will contain a liberal amount of iron, much larger than would be found desirable for constant potential machines. Such a dynamo is already in demand, and it will find an immediate field for the lighting of large cities.

THOUGHTS ON COSMICAL ELECTRICITY.

BY ELIHU THOMSON.

[*A lecture delivered before the Electrical Section, December 19, 1893.*]

Having been requested to speak to the Electrical Section of the Institute on some subject, it occurred to me that I might take the opportunity to present a few thoughts in the nature of speculations on the electrical relations of the earth and the heavenly bodies.

Where we have no definite knowledge we are forced to speculation, and often scientific speculation points the way to further advances in our theories. While speculation is not science, science is often benefited by speculative ideas; speculation is the result of imagination, science of investigation.

We know but little as yet regarding the actual facts in the study of cosmical electricity. We do know, however, that there is every reason to believe in the existence of electrical disturbances in space, and either proceeding from or concentrated by the bodies in the solar system.

We have, indeed, much to learn, and the difficulty of learning is the greater as we are called upon, in this case, to apply known principles to conditions comparatively unknown and difficult of conception by our mental powers. As an illustration, I may mention the paradox of the canals of Mars. Of all the planets, Mars is the one which appears to be like the earth, and, therefore, is the one, the phenomena of whose surface, it would seem, should yield most readily to interpretation. But we are puzzled at the very outset. So, also, it must be with a subject such as I have chosen for my talk to-night.

It is known that as we leave the surface of the earth and rise in the air, there is an increase of positive potential with respect to ground, such that on the top of the Washington Monument it may be 3,000 to 4,000 volts, and on the Eiffel Tower as much as 10,000 volts. On high mountains similar high potential differences are found. If the increase were equal to 1,000 volts for each 100 feet on the average, it would equal, at twenty miles altitude, about 1,000,000 volts, and from this it might be inferred that the conducting vacuous layer of rarefied air at great altitudes would possess a very considerable positive potential with respect to ground.

But just here we are confronted with a difficulty. It is not clearly proven that a pure gas, rarefied or not, can receive and convey a charge—solid or liquefied particles in it might readily do so, but there are considerations which seem to negative any assumption that gas molecules can themselves be charged.

If we imagine a charged drop of water suspended in air and evaporating, it follows, that, unless the charge be carried off in the vapor, the potential of the drop would rise steadily as its surface diminished and would become infinite as the drop disappeared, unless the charge were dissipated before the complete drying up of the drop by dispersion of the drop itself, or conveyance of electricity by its vapor. The charge would certainly require to pass somewhere and might leave the air and vapor charged. However this may be, the vacuum outside of our atmosphere is probably per-

fect, and, therefore, a perfect insulator. The ether itself appears to be the best insulator, or most nearly perfect non-conductor of electricity.

It is customary to speak of a charged body—this metal ball insulated in air, for example—as a thing by itself, but we well know that its capacity to receive a charge depends on the thickness of the surrounding dielectric, or the nearness of other conducting surfaces, such as the walls of the room, the floor and ceiling and other objects about it. The insulated ball is none the less one of the coatings of a condenser, the capacity of which depends on the thickness of the dielectric layer separating it from those objects or surfaces which form virtually the other coating.

It is doubtful then if a single body, in unlimited space, would be able to receive a charge of electricity, and it follows that even very large bodies like the earth and stars, separated as they are from one another by immense distances, cannot have much capacity. A comparatively small amount of electricity would give a very high potential in such a case.

It becomes an interesting question, just here, whether the fact that a charge resides only on the surface of a charged sphere or conductor, is due to attraction of opposite charges of sphere and surrounding objects, or to repulsion of like charge in the sphere, or to both. A simple consideration will show, I think, that it is due to both causes, and that lines of electrostatic induction joining oppositely charged surfaces and traversing the dielectric between them, are like lines of magnetic force, in that they both tend to spread laterally and also to shorten their paths. Their actual course, as is the case with the lines of magnetic force, will be determined by the resulting balance between both tendencies. Thus in *Fig. 1*, if two opposed surfaces *A B* are charged relatively, and then the surfaces be extended laterally, as indicated by dotted lines, and the extensions be of receding character, as shown, the charge will distribute itself over the added surfaces by virtue of the lateral spreading of the lines, while in doing this the actual length of the lines is increased.

Now, returning to the case of the earth, its capacity as a body insulated in space could not be very great, and a moderate amount of electricity in coulombs would give it a high potential. Viewed in another way, however, the earth may possess a much greater charge, or amount, of electricity. The solid earth itself is a conductor, the dense air around it a good insulator and dielectric layer, the rarefied air above a quasi-conductor in the sense that it can at small potential differences distribute a charge or convey a current, and the ether outside is a perfect insulator.

The earth may then possess the character of a huge conductor, the outer coating being rarefied conducting air, the inner coating, the ground and water surface and the dielectric the dense air between. The outer layers may

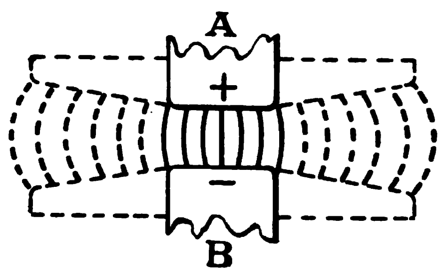


FIG. 1.

possess a potential, positive with respect to the earth's body, of, perhaps, as much as 1,000,000 volts.

Prof. H. A. Rowland has shown, however, that a moving charge is equivalent in magnetic effects to an electric current representing a similar transfer of electricity, and that a rotating charged air condenser produces that magnetic field which would be due to a current going in the direction of the moving changes on each plate. Applying this to the earth considered as a huge revolving condenser, *Fig. 2*, the dense air layer *A A A A* would become magnetized from pole to pole, and the velocity of the equatorial portion being so much greater than that of portions near the pole, would allow the magnetic lines to dip on each side of the equator in short-circuiting themselves through the solid earth *E*.

Moreover, the magnetic field so produced does actually correspond in direction of polarization with that which would be given when the outer coating *V V* is positive to the inner *E*, thus confirming so far the hypothesis which I have ventured to present to your consideration. It is merely a thought, and would need comparison of many data to give it a secure basis as a theory.

Any action which would disturb the charge of the con-

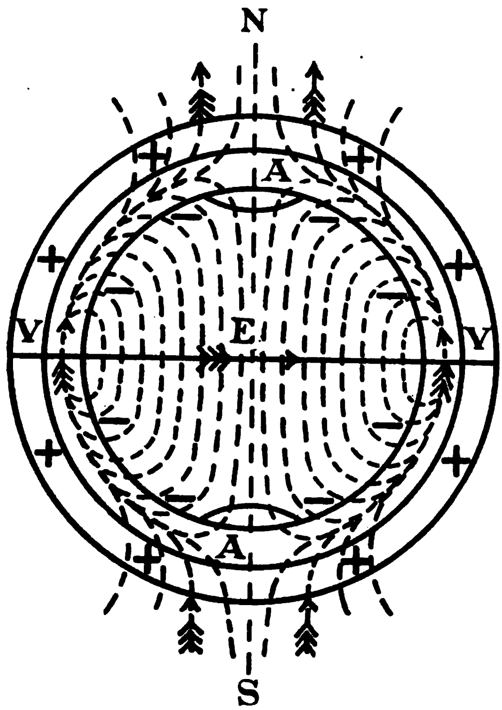


FIG. 2.

denser earth, would strongly affect the earth's magnetism and auroras especially would do so. They appear to represent a distribution of charge in the outer layers of the earth's atmosphere.

Assuming the earth to be a huge charged condenser, a thunder-storm might be brought about by a flow in the dense air dielectric, due to the presence of clouds of condensed vapor, extending to great altitudes. They may be

the auroral actions repeated in denser air, giving spark discharges, where in the aurora the diffused vacuum discharge only is seen.

The enormously high potentials exhibited in the thunderstorm may be secondary effects, due to coalescence of many minute drops of water charged to only moderate potentials, the reduction of surface raising the potential. It may in part be due also to evaporation of charged drops in some parts of the cloud, again reducing the surface and raising the potential.

The electrostatic induction of innumerable drops in a cloud, each drop possessing a like charge, gives virtually the effect of the possession by the cloud, considered as a whole, of a very much higher potential than is possessed by a single drop.

There must be some influence constantly at work to cause and maintain the positive potential of the higher layers of the atmosphere, for otherwise in various ways there would naturally be brought about an equalization of the charges of air and earth. Many theories have been proposed to account for the positive electrification of the air in its upper layers, and it may be that the condition is the result of a combination of causes rather than of any single cause. It is a legitimate thought, it appears to me, that the electrification may in large measure be due to influences outside of the earth itself. Let us assume a vast nebulous mass as having been the origin of the solar system by cooling and condensation, according to the nebular theory, and if for any reason that nebulous mass have a small charge or be at a potential difference with respect to other gaseous masses in space, the diminution of surface during shrinkage would gradually increase the potential of the charge, provided it could not escape through the surrounding ether. This charge would increase in potential until the finer particles on the outside of the mass were repelled outwards with a force equal to their centripetal tendency or gravity. A dispersion of such particles would ensue, and result in a fall of potential. The dispersion and accumulation of charges would occur periodically, while the hot mass of gas was shrinking and the par-

ticles sent off would be condensed vapors, liquid or solid, forming a charged cosmic dust proceeding in a radial direction from the central mass, just as the carbon sent out from a filament of an incandescent lamp leaves the filament radially after having condensed from vapor to solid carbon immediately at the surface of the filament, owing to the instant loss of the heat necessary to keep it vaporous.

Now the distance between the sun and a planet, such as the earth, is so great, that it is not probable that any considerable static—inductional effect could exist between them, even if they were at great differences of potential. On the other hand, electrified particles repelled periodically from the sun would reach the earth's atmosphere. It has been suggested that the coronal streams seen during total eclipses, particularly during the active or sun-spot period, may consist of electrified particles leaving the sun. If so, their lack of visibility, beyond a few diameters from the sun, would not forbid the assumption being entertained as a rational one, that the streams may pass outward indefinitely until they encounter some obstacle like the earth. But auroral displays on the earth are frequent only when the solar activity is greatest, when the coronal streams extend outwardly the farthest, and there appears to be a distinct connection between the presence of large spots on the sun's surface and auroral disturbances here.

Can we not consider that during an aurora the earth is passing through a coronal stream and developing, as it were, a secondary aurora, either by directly encountering in space the electrified particles from the sun, or by induction from streams of such particles near the earth's course?

Taking these thoughts in connection with the idea of the cause of the earth's magnetism presented above, it will be easy to understand why magnetic disturbances should be prominent during auroras. Taking also the fact that the sun is a charged body, and probably the planets also, it will be understood that some influence on the earth's condenser charge would exist, varying according to the positions relatively occupied by these bodies, and particularly of earth and sun. This in turn would give rise to magnetic variations,

such as the diurnal, annual and secular variations. It would account for the fact that the diurnal variations are greater when the earth is nearer the sun than when more remote,

My thought then, is, that the sun may be a charged body insulated in space, and, that owing either to a periodical accumulation of charge up to a certain critical potential, which would repel the outer particles into space and so relieve itself, or, to thermal disturbances occurring periodically during the cooling, the sun-spot period, or active period, recurs every eleven years, deforms the sun's outline, so far as the outer atmosphere is concerned, and raises the potential or the projecting parts to a degree to cause repulsion of particles; continuing until a certain discharge is effected, after which there is quiescence again.

During these actions the earth passes through, or near to, electrified streams and an aurora, or earth corona, is developed.

Concerning auroras, it would appear from observations of the great displays that the crown, or corona, seen in the zenith, is merely a view of bundles of streamers *on end*, and that the streamers in the north while nearly radial to the earth, are seen in perspective, rapidly changing their shapes and positions, while to the east and west are seen as comparatively stable but less defined streamers—an average view of great masses extending hundreds of miles and made up of innumerable changing streams of which the luminous effect is nearly steady. The grandest aurora which ever came under my personal observation was that of April, 1883, which reached its maximum between twelve and one o'clock. The whole horizon was in view as I was on top of a hill, and it is no exaggeration to say that the whole sky from north to south horizon and from east to west, was filled with auroral streams of wonderful coloring. The crown in the zenith was a marvellous display of changing light, changing positions, changing intensity and changing color. The streamers in the north were sharply defined like great bundles of luminous needles and seemed almost within reach. They changed rapidly, were remarkably brilliant and covered an angle from about 20° altitude

almost to the zenith. The stars, even of the first magnitude, could scarcely be seen, and although there was no moon, the time could easily be read on a watch, and the roofs of buildings, ten miles away, could easily be distinguished. I mention this aurora particularly because it showed in a most striking way the characteristics stated above, as indicating the radial position of the streamers. On no other theory could the zenith crown and streamers be seen simultaneously at places hundreds of miles east and west and many miles north and present substantially the same appearance.

It would appear that auroral displays are either much more rare in the southern hemisphere or absent altogether. Speaking on the subject with Dr. Gould, of Harvard University, he informed me that, although he had lived in Chili for fifteen years and was constantly on the watch for auroras, he never in that time saw a single display.

Now, if a discharge is taking place under critical conditions in a high vacuum, the relation of its path and direction to a magnetic field in the vacuum may determine the continuance or cause a stoppage of the discharge, according to the direction of magnetic polarization. Or, a stream of electrified particles may be deflected by a magnet, as shown in the well-known Crookes tubes. From this it might follow that the magnetism of the earth may be inhibitory to the discharge in the southern hemisphere and favorable to it in the northern, in which case the relatively greater frequency of the aurora *borealis* would be explained.

It has been found as a result of recent investigations that a negatively charged body will, if exposed to violet light, dissipate its charge to surrounding bodies, probably by sending off atoms, molecules or particles of its own substance negatively charged.

A positively electrified body placed in the neighborhood of a body maintained at a negative potential under violet light, is soon discharged by the negatively electrified particles coming to it from the negative body even when the positively charged body is not in the light. Whether this dissipation of negative charges would take place in the

ether itself, or in a very high vacuum, is, so far as I am now aware, not known. Evidently, however, such an action would have a very marked influence on the retention and distribution of charges on the earth.

If the sun's charge be positive and positively electrified particles are sent out in the coronal streams, it would be easy to understand that the outer earth charge might be kept up from the sun and that not only auroras, but thunderstorms also would be more frequent during periods of solar activity. Observations tend, I think, to show that such is the case.

Again, if the sun be a highly electrified body, might it not be possible that cometary masses may owe some of their illumination to redistribution of electricity as they approach towards and recede from the sun, or to encounter with electrified particles leaving the sun? Here, again, the radial direction of the comet's tail is suggestive, as are also the rapid changes which the comet undergoes.

And lastly, as a concluding thought, we may ask whether the phenomena of the sudden appearance of a star, which, after reaching great brilliancy, fades out in a few days or weeks, may not be referred to electrical causes, such as the equalization of charges on near approach of two bodies, attended as it must be with an enormous evolution of light, gradually fading away as the vapors cool after the discharge. Thus, some of the temporary stars may possibly be explained.

In conclusion, I beg to remind you what I have offered you here are only thoughts, not theories—which a careful comparison of all the facts may serve to confirm or to discredit. Objections may arise, but oftentimes what seems an insuperable objection disappears in the light of more complete knowledge and observation. It is true that the thoughts presented are not all new, and it is only the more gratifying when others may have arrived at similar guesses. Though generally busy with the practical side of electrical science, it is a source of pleasure sometimes to let one's thoughts have full play, even if the result be only a maze of speculation, some part of which may prove to be fallacious.

Course of Lectures

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THE AUSPICES OF THE

Electrical Section

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PHILADELPHIA.

SESSION 1893-'94.

To those interested in....

Theoretical and Applied Electricity.

THE Electrical Section of the Franklin Institute is the only organized body in the City of Philadelphia giving special attention and encouragement to the advances in theoretic and applied electrical science. Entering now upon the third year of its life its record of steady numerical growth and the constantly higher character of its papers and discussions are sufficient evidence of its usefulness and warranty for its existence.

The meetings of the Section are held in the Hall of the Institute on the evening of the fourth Tuesday of each month, except July and August, at 8 o'clock. At these meetings papers dealing with various electrical topics are read by members most competent to deal with them and discussed by the Section. It has been the aim of the programme committee to so arrange these papers as to satisfy both the requirements of the technical and the scientific man. It is believed that these papers and their discussion has exercised a healthful influence in the electrical field, and upon electrical work in Philadelphia in particular. Furthermore the meetings of the Section have brought together many interested in electrical matters who might otherwise never have met, and has promoted social relations among them of great value.

The programme committee by direction of the Section, has introduced a novel feature into the work for the ensuing year which it is believed, will prove very attractive. This feature is the securing for *every other* meeting of the Section, of a paper or lecture by a man eminent in the electrical field, thus broadening the work of the Section, and increasing its value to the electrical fraternity and its own members, besides lessening the labor hitherto entailed upon the Philadelphia members. A list of the lectures and subjects as finally arranged is printed herewith. Besides these papers a number of others of the highest interest and importance may be expected during the year from our city members.

In order that the work of the Section may be made as widely useful as possible, the active co-operation of all those interested in any branch of Electrical Science or Engineering is greatly desired, and members are requested to lay the matter before their friends, and to secure their services to the Section.

Those desiring to join the Section may make application through the Secretary of the Section or of the Institute, or through any member of the Section.*

Each member has the privileges of the Institute Library, and receives, without extra charge, a copy of the printed Annual Proceedings of the Section. The proceedings alone are well worth the outlay in fees, the last volume having contained 17 papers and 215 pages. It is expected that the proceedings for this year will be considerably larger and of greater value.

Any further information may be had by addressing

ELMER G. WILLYOUNG, *President*,
817 Filbert Street, Philadelphia,

or ROBERT H. LAIRD, *Sec'y and Treas.*
518 Girard Building, Philadelphia.

* BY-LAWS. ARTICLE I, SECTION 1.

In accordance with Article XI, Section 4, of the By-Laws of the Institute, only members of the Institute may be elected to membership in the Section, but Sections are empowered to appoint Associates, Corresponding and Honorary Members, provided that such appointments are sanctioned by the Board of Managers. Associates shall have the privilege of attending the meetings of the Section, and of participating in its scientific discussions, but shall not be entitled to vote.

...LECTURES...

Thoughts on Cosmical Electricity. (Illustrated.)

SPECIAL LECTURE.

Prof. Elihu Thomson, (Hon. Member,) Tuesday, December 19, 1893.

Electrician General Electric Co.

The Theory and Design of the Closed Coil Constant Current Arc Dynamo.

Prof. H. S. Carhart, (Hon. Member,) Tuesday, December 26, 1893.

Professor of Physics and Electrical Engineering, Univ. of Michigan.
Pres. Jury of Awards, Dept. of Electricity, World's Columbian Exhibition.

Telephony.

Mr. J. J. Carty, Tuesday, February 27, 1894.

Electrician Metropolitan Telephone and Telegraph Co.

Magnetic and Dielectric Viscosity.

Prof. M. I. Pupin, Tuesday, April 24, 1894.

Professor of Pure Science, Columbia College.

Dr. Wm. J. Morton, New York City, Tuesday, June 26, 1894.

The title of this lecture can not yet be announced. It will deal with some aspect of or subject connected with Electro-Therapeutics, in which field Dr. Morton is a recognized authority.